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FURTHER TESTS OF THEORIES OF DECISION IN AN "EXPANDED JUDGMENT" SITUATION

FRANCIS W. IRWIN AND W. A. S. SMITH[1]

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According to the theory of decision developed by Cartwright and Festinger (**1, 2, 3**), the presentation of two stimuli for a comparative judgment arouses within *S* tendencies to make each of the responses that are permitted. In a two-category situation, these might be, e.g., the tendencies to say "greater" and to say "less." The strength of these opposed tendencies and that of their algebraic sum, the resultant tendency, is supposed to vary randomly in a normal distribution with the passage of time. Opposed to this resultant is a certain restraint against making a decision. When in its fluctuation the strength of the resultant happens to be greater than the strength of the restraint, a decision takes place. The mean of the distribution of resultants depends upon the size and direction of the stimulus difference, but the determiners of the variability of this distribution have not been discussed by Cartwright and Festinger.

Irwin, Smith, and Mayfield (**5**) have argued that this theory leads to certain predictions concerning *S*s' confidence in their judgments that are highly implausible in light of the processes whereby statistical decisions are made. Assuming that the decision process involved accumulating information with the passage of time, they arrived at several quite different predictions and were able to confirm each of them experimentally in an "expanded judgment" situation.

A further contrast between the two views appears when one asks what predictions they would make about the determiners of the duration of decision times if *S* were left free to announce his decision at his own pleasure (as in all standard psychophysical procedures). One such determiner would presumably be the size of the stimulus difference. Cartwright and Festinger would suppose that the larger the difference, the sooner on the average the value of the resultant tendency would fall beyond the range of restraint and a decision therefore be made. The proposed alternative view would expect the same outcome on the grounds that the larger the difference, the sooner he would make his decision, as would be true in making a statistical decision. Thus, the two theories would make the same prediction, on different grounds, for the effects of varying the stimulus difference. However, if it were possible to vary the variability of the response tendencies,

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it appears that the two views would lead to opposing predictions. Cartwright and Festinger must predict that the decision time would be inversely related to this variability, since the greater the variability, the larger would be the proportion of the distribution of resultants that fell beyond the range of restraint against making a decision, and conversely, the less the variability, the smaller would be this proportion. On the other hand, the other view leads one to expect the decision time to be directly related to the variability of the resultant, since, by analogy with statistical processes, the smaller the variance of the data, the sooner a decision would be reached.

The object of the present experiment was to test these predictions concerning the relation of magnitude of stimulus difference and the variability of resultant tendencies to decision time. It is already well known that decision time is inversely related to stimulus difference, as is predicted by both theories. However, to test the effects of the variability of the resultant tendencies it was necessary to use a modification of the expanded judgment situation referred to above. Since this involved an argument from analogy, it was desired to show that a well-known effect would exhibit itself in the analog in order to strengthen the argument when a previously untested effect was at issue.

In its present version, the expanded judgment situation involved showing *S* a series of cards upon each of which a number was printed. The cards were drawn from a large pack that contained numbers distributed approximately normally with known mean and *SD*. The *S*'s task was to observe these numbers and to tell *E* when he had decided that the mean *of the whole pack* was greater than, or less than, zero. A judgment of zero was not permitted. The primary data consisted of the numbers of cards required by *S*s to make such decisions. Each instance in which *S* observed a series of cards and made a decision was regarded as analogous to the process of making a single psychophysical judgment, with the numbers on the cards corresponding to the values of the hypothetical "resultant tendencies" and the number of cards required for the decision corresponding to the decision time.

Method

Subjects.—The *S*s were 30 students in psychology courses at the University of Pennsylvania who served as volunteers, of whom 9 were men and 21 were women. Most of them were in an introductory course in psychology, and none was acquainted with the purpose of the experiment. Two had had part of a course in statistics and one had had a year of this subject, but nothing was observed to distinguish their results from those of other *S*s.

Materials.—Eleven packs of cards 2.5 by 3 in. in size were used. Each pack contained 100 cards upon each of which was printed a number, positive, negative, or zero. The 100 cards in a pack were made up of 10 sets of cards identical except for their order within the set, so as to avoid large discrepancies between the mean and *SD* of the cards seen by *S* and the corresponding values for the pack as a whole. Since the sets of 10 cards were kept segregated, *S* saw first the cards of the first set, then those of the second set, etc. If more than 100 cards were required, *E* started again with the first set. The *S* and *E* were separated by a low screen that prevented *S* from observing any of these arrangements. At the beginning of the experiment, the cards in each set in each pack were thoroughly shuffled. The resulting card order was employed with 20 *S*s, while the reverse order was used with the other 10 *S*s.

A practice pack was made up of sets each of which had a mean of 2.0 and an *SD* of 2.0, the distribution being as nearly normal as possible for 10 cards with the interval used. Of the experimental packs, two each had means of 1.5, .5, 0, − .5, and − 1.5; one of each of these pairs had an *SD* of 2.0 and the other an *SD* of 7.5. The numbers used for the two packs with means of zero were: 3.5, 2.0, 1.5, 1.0, 0.5, − 0.5, − 1.0, − 1.5, −2.0, −3.5 (*SD* = 2.0); 13.0, 8.5, 5.5, 3.0, 1.0, − 1.0, −3.0, −5.5, −8.5, − 13.0 (*SD* = 7.5). The numbers in the other packs differed from these by constants equal to their means.

Procedure.—The *S*s were seen individually. Instructions were given as follows:

"As you know, many experiments have been done to find out how well people can detect small differences in color or sound intensity or weight, and so on. The experiment we are going to do is something like this; but it is different from

anything that has been done before because we want you to detect small differences when we use numbers instead of lights or sounds or weights.

"Here is the way it works. I have several packs of cards, each of which has 500 cards in it. Here is one of these packs. [A dummy 500-card pack was exhibited.] As you see, each card has a number on it. Some of the numbers are positive, like this [a positive card was shown] and some are negative, like this [a negative card was shown]. All 500 cards in the pack have been thoroughly shuffled, so that they are in a purely chance order.

"Now, I am going to show you some of the cards from this pack, one at a time. Your job is to look at each number carefully and to try to detect, on the basis of the numbers that you see, whether the average of *all 500 numbers in the whole pack* is *greater than zero* or *less than zero*. I will show you as many cards as you like, but you are to tell me as soon as you have made up your mind whether the average of *the whole pack* is greater than zero or less than zero. If you decide that it is greater than zero, stop me and say *plus*; if you decide that it is less than zero, stop me and say *minus*. Do you understand?"

The instructions were then summarized, repetitions were given if needed, and the experimental procedure was run through with the practice pack. Cards were exhibited by *E* at a rate of about 2.5 sec. each. Further instructions or clarifications were provided during the practice procedure when necessary. The *E* then proceeded with the experimental packs, which were used in a different irregular order for each *S*, the orders being arranged so that each pack appeared equally often in each serial position.

Results and Discussion

The mean numbers of cards required for the 30 *S*s to reach a decision as to the direction of the departure of the mean of the pack from zero are plotted in Fig. 1. It can be seen that, in accordance with both theories, the number of cards required is directly related to the absolute value of the mean of the cards. The analysis of variance given in Table 1 shows that the effect of the size of the mean is highly significant ($P < .001$). With respect to the *SD* of the cards, Fig. 1 and Table 1 show that the number of cards required was consistently and significantly greater for packs with large *SD* than for those with smaller *SD* ($P < .001$). This agrees with the prediction from the theory proposed here, but it is contrary to the Cartwright-Festinger prediction if the latter is properly tested by the expanded judgment situation.

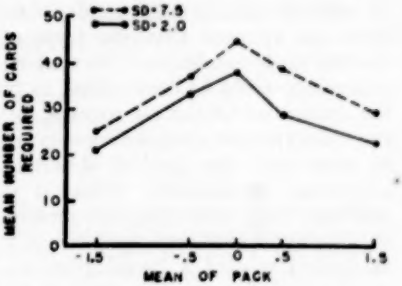

Fig. 1. Mean number of cards required for decision as a function of the mean of the cards and the *SD* of the cards.

Large and consistent individual differences appeared in the results, and Table 1 indicates that they, too, were highly significant ($P < .001$). The mean number of cards required per pack ranged from 7.6 for one *S* to 107.7 for another. The existence of these individual differences is not inconsistent with either theory. Cartwright and Festinger would presumably expect *S*s to differ in degree

TABLE 1

Analysis of Variance of Number of Cards Required for Decision

Source	*df*	*MS*	Error Term	*F*
1. Mean (M)	4	3494.0	4	25.7*
2. *SD*	1	3162.3	5	16.2*
3. Subjects (*S*)	29	4906.1	7	26.5*
4. M × *S*	116	135.8		
5. *SD* × *S*	29	194.8		
6. M × *SD*	4	136.3		
7. M × *SD* × *S*	116	185.0		
Total	299			

* $P < .001$.

of restraint against making a decision, while we suppose that the level of confidence demanded by *S* for making a decision would be determined, as in the analogous statistical process, by the values he put upon different types of error and the cost of obtaining additional information. While it is believed, from observing the present *S*s, that those who were most strongly motivated toward a "good performance" used the greatest numbers of cards, there are no objective data on this point.

The process by which the *S*s in this and the previous experiments (**5**) formed judgments of the value of the mean of a series of numbers might be thought of as the development of an "adaptation level" in Helson's (**4**) sense. However, it is believed that this concept cannot account for the effects of the *SD* of the cards upon the number of cards required for a decision in the present experiment or the effects upon confidence of the mean and *SD* of the cards and the number of cards seen, in our earlier experiments. The adaptation level has the characteristics of an average of stimulus values; as an indifference point, it separates a continuum of stimuli into those above it and those below it. However, to account for the present and previous (**5**) data, it would need to have some additional property such as, perhaps, "strength," since *S*s behave quite differently with packs of cards that have the same mean (and therefore produce similar adaptation levels) when the *SD*s of the cards or the numbers of cards seen are varied.

Summary

The *S*s were shown numbers on cards drawn from large packs in which the means and *SD*s of the numbers varied from pack to pack, and were required to announce when they had decided that the mean of the whole pack was greater than, or less than, zero. The number of cards required for these decisions varied directly with the absolute value of the mean, as predicted both by the Cartwright-Festinger theory of decision and by a theory based upon the processes of statistical decision-making. However, the number of cards required was greater for the greater of the two values of *SD* that were used, which confirmed the "statistical" theory but contradicted the Cartwright-Festinger theory to the extent that the latter was applicable to the experimental situation.

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EFFECTS OF CONTIGUITY AND SIMILARITY ON THE LEARNING OF CONCEPTS [1]

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The purpose of this study was to test two hypotheses. The first was that greater temporal contiguity among representations of the same concept will lead to faster learning of that concept. The expectation is that the closer together within a list are representations of the same concept, the greater will be the likelihood that responses made by *S* to the concept-relevant features of the stimuli will be contiguous. Since it is assumed that contiguity of these responses is fundamental to concept learning (cf. **5**), learning should proceed more rapidly the closer together are stimuli of the same concept.

The second hypothesis states that greater similarity among the relevant concept cues of different concepts will lead to slower learning of these concepts. This is an extension of Gibson's (**2, 3**) attempt to employ the concept of stimulus generalization to explain retardation of learning due to the effects of intratask stimulus similarity. The theory holds that as similarity increases among the relevant concept cues of different concepts, generalization likewise increases. This would result in a greater number of errors made during learning, and in slower learning of the concepts involved.

[1] This paper is based on a dissertation submitted to the Graduate School of Northwestern University in partial fulfillment of the requirements for the Ph.D. degree. The author is indebted to Dr. Benton J. Underwood for his many helpful suggestions and guidance during the course of the study.

[2] Now at Maintenance Laboratory, Air Force Personnel and Training Research Center, Lowry Air Force Base, Colorado.

METHOD

The procedure was typical of that used in paired-associate learning except that (*a*) it was the task of *S* to learn concepts, and (*b*) precautions were taken to prevent rote learning of the lists. A standard Hull-type memory drum was used. Each *S* learned a practice list and one of six experimental lists.

The practice list.—This list was the same as that used by Oseas and Underwood (**4**). The concept examples consisted of circles, squares, and triangles of different sizes (large, medium, and small) and different shades (black, gray, and white). The concepts of this list were the nine possible combinations of three sizes and three shades. Each of the nine concepts was identified by an arbitrarily selected letter.

The experimental lists.—The stimuli were red, green, or blue lines ¾ in. long, pointing at different azimuths and accompanied at the right by one, two, or three black dots at the top, middle, or bottom of the line. The concept determinants were the azimuths made by the line in combination with the position of the dot(s). In each list, three azimuths and three dot positions were used, each dot position combining with each azimuth to form a separate concept. There were thus nine concepts. The colors of the lines and the number of the dots were the distractors (the irrelevant characteristics of the stimuli). Each color-number combination appeared once with a representation of each concept. Nine different examples of each concept were therefore possible. Since there were 9 concepts and 9 representations of each concept, each list consisted of 81 stimuli. A group of 9 of these 81 examples was arbitrarily called a trial. Each concept was named by a different letter of the alphabet.

Method of varying similarity.—Three points along a continuum of similarity were chosen and two along a scale of contiguity to produce a 3×2 orthogonal design.[3] In manipulating

[3] The original study employed a 3×3 orthogonal design in which there were three Contiguity conditions (Very High, High, and Low) as well as three Similarity conditions. Detailed analysis of the data indicated quite conclusively that performance of the *S*s in the Very High Contiguity groups was to some extent

TABLE 1

AVERAGE DISTANCE BETWEEN PAIRS OF REPRESENTATIONS OF A CONCEPT FOR BOTH CONTIGUITY CONDITIONS (THREE-TRIAL SERIES)

Pairs of Representations	Contiguity Conditions	
	High	Low
X_1–X_2*	4.55	9.00
X_2–X_3	4.55	9.00
X_3–X_4	17.90	9.00
X_4–X_5	4.55	9.00
X_5–X_6	4.55	9.00
X_6–X_7	17.90	9.00
X_7–X_8	4.55	9.00
X_8–X_9	4.55	9.00
X_9–X_{10}	17.90	9.00

* To be read: From the first representation of Concept X to the second representation of Concept X, etc.

similarity, the azimuth of the line was varied so that in Cond. I and II, the three sets of azimuths were at 0°, 6°, and 12° (high similarity); in Cond. III and IV, the azimuths appeared at 0°, 9°, and 18° (medium similarity); while in Cond. V and VI azimuths appeared at 0°, 12°, and 24° (low similarity). Previously the author had determined that under conditions similar to those of this study a difference in azimuths of as small as 2° could be perceived correctly 75% of the time.

Method of varying contiguity.—In each group of nine trials, nine representations of each concept appeared. The mean distances between each consecutive pair of representations of a concept are presented for each contiguity condition in Table 1. It will be noted that under both conditions of contiguity, the mean distance between any two representations of the same concept (e.g., X_1 and X_2) is 9.00 stimuli. The manipulated variable, then, is not the average distance between representations of the same concept, but rather the closeness of grouping of the three representations of a concept in a three-trial series.

Subjects.—To each of the six cells, 20 *Ss* were randomly assigned (120 total *Ss*). The *Ss* were drawn from psychology classes at Northwestern University. None had served previously in a concept-learning experiment.

Experimental design.—Each *S* appeared at the same hour on two successive days. In the first session, Cards 5 through 16 of the Pseudo-Isochromatic Test for Color Perception were shown. Those who made responses made only by the "red-green blind" were released from further participation in the experiment. The instructions, aimed at defining the concept-learning task, and at discouraging learning by rote, were then read by *E*. After *S* had indicated in response to questions by *E* that he understood his task, learning of the practice list was begun. Learning was by the anticipation method. For 3 sec. the stimulus representation of the concept appeared alone. For an additional 3 sec. the stimulus appeared with its concept name. Learning continued until *S* had responded correctly for one complete trial (i.e., to one example of each of the nine concepts). The *S*'s score on the practice list was the number of the trial immediately prior to the completely correct trial. Only those who learned by Trial 46 were asked to return for the second day.

In the second session, *S* learned the experimental list for the group to which he had been assigned. All *Ss* remained for 45 trials. At the end of Trial 35, *Ss* were told that 10 min. remained. During learning of both practice and experimental lists, *E* recorded all verbal responses to the stimuli.

Performance measures.—(*a*) Number of concepts learned—a concept was considered as learned when *S* responded nine consecutive times to the representation of that concept. The nine-consecutive response criterion was used so that *S* would have responded correctly to each of the nine different representations of that concept. (*b*) The number of within-list intrusions occurring during Trials 1–45 on the experimental task was employed as a second criterion measure.

RESULTS

Practice performance.—The *Ss* were assigned randomly to the six experimental groups. The results of an analysis of variance of performance data for the practice list ($F < 1.00$) indicate that these groups did not differ significantly in ability to learn the concepts of the practice task. Since, however, performance on the practice task did not correlate highly with performance on the experimental task (rho varied from $-.10$ to .46 for various groups and for various performance criteria) the interpretation of the results for the experi-

artifactual. Data for these groups have thus not been included in the analyses presented in this paper.

TABLE 2

NUMBER OF CONCEPTS LEARNED

Similarity	Contiguity			
	High		Low	
	Mean	*SD*	Mean	*SD*
High	4.90	3.70	4.50	3.05
Medium	6.40	2.85	4.25	2.75
Low	7.45	2.50	4.75	3.60

mental lists rests on the assumption (untested) that the groups were random samples from the same population.

Number of concepts learned.—Table 2 shows the number of concepts learned, and Table 3 summarizes an analysis of variance of these data. The effect of contiguity is significant, but the effects of similarity and of interaction are not. The difference between high and low contiguity is significant ($t = 3.02$, $P < .01$).

Number of within-list intrusions.—Since Bartlett's test indicated that the variance between groups was heterogeneous ($P < .01$), a log transformation of the data was used. Chi square for the transformed data (cf. Table 4) was 1.94 ($P > .05$).

Analysis of variance of the transformed data (Table 3) revealed a significant F for contiguity ($P < .01$) though not for similarity or interaction ($P > .05$).[4] The t of 2.54 for the comparison between high and low contiguity was found to be significant ($P < .05$).

TABLE 3

ANALYSES OF VARIANCE: NUMBER OF CONCEPTS LEARNED AND NUMBER OF INTRUSIONS

Source	*df*	Concepts Learned		Log Intrusions	
		MS	*F*	*MS*	*F*
Contiguity	1	92.00	9.04**	.9530	6.37*
Similarity	2	19.50	1.92	.2614	1.75
Interaction	2	14.50	1.43	.3494	2.38
Within	114	10.10		.1461	
Total	119				

* $P = .05$.
** $P = .01$.

TABLE 4

NUMBER OF WITHIN-LIST INTRUSIONS (LOG-TRANSFORMED DATA)

Similarity	Contiguity			
	High		Low	
	Mean	*SD*	Mean	*SD*
High	1.7849	.3515	1.7805	.3845
Medium	1.6277	.4315	1.7850	.3195
Low	1.4306	.3610	1.8120	.3750

Errors made in learning the different concepts.—An analysis was made of the kinds of within-list intrusions occurring during learning of the different concepts. Three classes of intrusions were tabulated: those made to stimuli of the vertical, slight slant, and the extreme slant concepts. The data presented in Table 5 indicate

TABLE 5

DISTRIBUTION STATISTICS AND CORRELATIONS INVOLVING THREE TYPES OF INTRUSIONS

Stimulus to Which Intrusion Was Made	Intrusions		Variables	Differences		
	Mean	*SD*		*r*	*t*	*P*
1. Vertical	13.65	16.19	1 & 2	.70	11.39	.001
2. Slight Slant	29.60	21.34	2 & 3	.84	2.47	.05
3. Extreme Slant	26.94	18.70	1 & 3	.67	10.17	.001

the existence of generalization gradients on either side of the slight slant concepts. The slope on the side of the extreme slant concepts is much

[4] An analysis of variance for omissions was also computed. None of the Fs was statistically significant ($P > .05$).

shallower than that on the vertical side.

Discussion

The effects of contiguity.—The hypothesis under investigation states that the closer together temporally are the representations of the same concept, the more rapidly will that concept be learned. When analyses were performed in terms both of number of concepts learned and log of within-list intrusions, the *F*s for contiguity were significant ($P < .05$).

It was assumed that the prerequisite for concept learning was that the responses to the concept-relevant cues of two stimuli of the same concept be contiguous. It was anticipated that the variations in grouping of these concept stimuli would affect the likelihood that responses made by *S* to the concept-relevant features of these stimuli would be contiguous. For example, in the low-contiguity condition, *S* had to wait for 9.00 stimuli to appear between any two representations of the same concept. Thus, at least initially, the likelihood would be greater that the response(s) to the concept-relevant features of X_2 would be further separated in time from that to the concept-relevant features of X_1 than under conditions of high contiguity. And not only would these responses be less contiguous because of the passage of time per se, but also because responses to the stimulus features of representations of other concepts might have intervened. This would lead to an interference between responses (e.g., to X_1, Y_1, Z_1) and an even lessened likelihood that the response(s) to the concept-relevant features of X_1 would be contiguous to those of X_2. Thus concept learning would be slower and more errors would be made than under the high-contiguity conditions.

Effects of similarity.—It was anticipated that increasing similarity among the relevant concept cues of the different concepts would be accompanied (*a*) by an increase in the tendency for stimulus generalization to occur, and (*b*) by a concomitant increase in the differential reinforcement (i.e., reward of one response to a cue and nonreward of all other responses to the cue) necessary before the stimulus presentations would be discriminated and learned. The soundness of this principle has been demonstrated in previous verbal-learning and concept-learning studies (**1, 3, 4**).

The generalization hypothesis applied to this experiment implies two consequences: (*a*) The most errors would be made to stimuli of the slightly slanted concepts, and the fewest errors to stimuli of the vertically determined concepts. Generalization would occur in two ways: First, stimuli of the slight slant concepts would tend to be responded to as stimuli of both vertical and extreme slant concepts. Stimuli of the vertical concepts would be more likely to be responded to as those of the slight slant concepts than of the extreme slant. And similarly, stimuli of the extreme slant concepts would be more likely to be responded to as those of the slight slant than of the vertical concepts. Secondly, stimuli of the extreme slant concepts would be more likely to be responded to as those of the slight slant concepts than would stimuli of the vertical concepts, since the two slants are more similar to one another (i.e., they both slant) than are stimuli of the slight slant and the vertical concepts, even though the azimuth differences separating the slight slant concepts from those of the other two classes of concepts are the same. (*b*) Fewer concepts would be learned, and more errors made with the high-similarity lists than with the low-similarity lists, since high similarity would make differentiation between representations of different concepts more difficult.

In respect to (*a*) the use of stimulus generalization as an explanatory concept is indicated. Its use is not, however, indicated for (*b*) although the trends of means both for number of concepts learned and for the log of within-list intrusions are in the predicted direction.

It is not clear why the similarity variable did not result in differences in rate of concept learning. A possibility is that the points on the similarity dimension were too close together to allow

for the effects of similarity to be demonstrated. Thus, had three points more separated on the azimuth-difference continuum been employed (i.e., greater differences in azimuth variation than 6°, 9° and 12°), the effects of similarity (through the operation of stimulus generalization) might have been more clear-cut than was demonstrated in this study.

Summary

In this study the validity of the following hypotheses was tested: (*a*) The greater the temporal contiguity among representations of the same concept, the faster the learning of that concept, and (*b*) the greater the similarity among the relevant concept cues of different concepts, the slower the learning of these concepts.

A total of 120 *Ss* was randomly assigned to six groups of 20 *Ss* each of which learned a practice and experimental list. The experimental list consisted of line and dot combinations. The azimuth of the line (three azimuths) and the position of the dot(s) (high, middle, and low) were the concept determinants. The number of dots (one, two, or three) and the color of the line (red, green, or blue) were the distractors. Learning was by a modified paired-associate method. Three variations in similarity and two in contiguity were employed. Similarity was varied by changing the azimuth differences between the lines, contiguity by changing the cluster of the three concept representations in a group of 27 stimuli. The *Ss* were given 45 trials on the experimental list.

The following results were obtained: (*a*) Statistically significant effects of contiguity in terms both of number of concepts learned and number of intrusions during learning were demonstrated. (*b*) No statistically significant effects of similarity were demonstrated either in terms of number of concepts learned or of number of within-list intrusions during learning. (*c*) The most within-list intrusions were made to stimuli of the slight slant concepts, then to those of the extreme slant, and vertical concepts respectively.

It was suggested that closer grouping of representations of the same concept led to a greater likelihood that responses made by *S* to the concept-relevant features of this concept would be temporally contiguous. Grouping would also lead to a decreased probability of interference from responses to other concept stimuli. The concept of stimulus generalization was employed in explaining the frequencies of errors involving the three different classes of concepts. Finally, it was suggested that the points on the similarity dimension may have been too close together to lead to differences in the rate of concept learning.

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MAGNITUDE OF RESPONSE TO COMPOUNDS OF DISCRIMINATED STIMULI [1]

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This experiment tests the hypothesis that, with simple visual stimuli in an arrangement designed to minimize interaction of components of the visual field, the magnitudes of response to compounds of stimuli will be simple interactions of the response evocation properties of the component stimuli present.

Attempts to specify and interrelate stimulus variables in classical conditioning studies have emphasized the complex nature of such stimuli. These considerations led Pavlov and his associates (**4, 5**) to study the properties of purposefully compounded conditioned stimuli. This work stimulated Hull (**3**) to attempt a theoretical structure to explain what he called functional dynamics of compound conditioned stimuli and stimulus patterning.

The study presented here investigates the situation in which elemental stimulus components, composed of colored dots, are trained individually to different response evocation levels through classical conditioning techniques and are subsequently tested as combinations or compounds. Three classes of response training to the individual stimuli are used. One involves consistent reinforcement (pairing with an electric shock), the second involves consistent nonreinforcement, and the third involves stimuli not present during the training series but introduced as components during test series on combinations. Assuming transfer of response potential from components alone to components in combination, the following predictions with respect to order of magnitude of GSRs are made: (*a*) maximal when two reinforced stimulus components are tested as a compound; (*b*) least when a nonreinforced stimulus is presented with a stimulus of either of the other classes; and (*c*) intermediate when not-presented stimuli are paired with stimuli of other classes. Predictions regarding the class of "not-presented" stimuli are based on the assumption that since these stimuli operate as "strange" stimuli in the test situation, they will evoke a larger GSR than a stimulus which has been presented consistently without reinforcement.

A study recently reported by Schoeffler (**6**) tested a similar hypothesis employing probability of response in a motor task as the dependent variable. The hypothesis was formulated from the theory of Estes and Burke (**1**) to predict the probability of response in stimulus situations composed in part of stimuli to which this response had been conditioned, in part of stimuli to which an opposing response had been conditioned, and in part of stimuli to which neither response had been conditioned. The probability of a response in the presence of a given test pattern was found to be equal to the proportion of component stimuli

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[2] The senior author was responsible for the design of the study, analysis of data, and preparation of this report. The junior author gathered the data. Vsevolod Shmelev contributed computational assistance.

that were conditioned to that response.

Method

Subjects.—Thirty-two volunteers, 18 men and 14 women, from introductory psychology classes at the University of Southern California were employed as *S*s. Each received a small monetary reward for his participation.

Apparatus.—The GSR was measured as a DC resistance change in a Wheatstone bridge input to a DC amplifier (7) with changes recorded on an ink-writing milliammeter. The current through *S* was maintained at 25 microamperes. Responses were picked up by a zinc, zinc-sulphate, saline paste, skin junction employing ¾-in. diameter Lucite cup electrodes fastened by rubber straps to the palm and back of *S*'s nonpreferred hand.

The UCS was an electric shock delivered to the volar surface of *S*'s forearm (preferred) through two ¾-in. silver electrodes spaced 1½ in. apart. The shock was generated by the single discharge of a .1-mfd condenser, charged to 90 v. and discharged through the primary of a 1:18 ratio transformer. Intensity was controlled by a voltage divider in the secondary of the transformer. The strength of the shock was adjusted for each *S* to meet a double criterion: the consistent production of a GSR and a verbal expression of slight discomfort by *S*. In a few doubtful cases a criterion of a consistent finger twitch upon stimulation was substituted for the verbal expression of discomfort.

The CS consisted of ¾-in. diameter colored dots projected on a ground-glass screen 30 in. in front of *S*. Wratten filters in masked 2 × 2-in. slide mounts were built up by neutral absorbing media to produce uniform response on a barrier layer-type photronic cell. Four colors were employed, red (Wratten A, No. 25), green (B2, No. 58), blue (C5, No. 47), and yellow (K2, No. 8). To reduce projector lag in short exposures, a resistor arrangement kept the bulb filament continuously hot.

Time relations among stimuli were controlled by a pair of Hunter electronic timers. The CS preceded the UCS by .5 sec., and remained on .5 sec. following the onset of the UCS. The recording device was provided with signal magnets to indicate onset and cessation of both stimuli.

Instructions.—All instructions were administered in writing. They briefly described the GSR, the nature of the CS and UCS, and what *S*s were required to do. Specifically, *S*s were asked to attempt to anticipate each stimulus before it was presented to them. During the training period a "ready" signal was called out by *E* and *S* was expected to anticipate aloud the stimulus. At the beginning of the testing period, *S* was told that it was no longer necessary for him to predict aloud the stimulus.[3]

Procedure.—Observations were made in a soundproof room of low illumination. A partition separated *E* and the equipment from *S*, and an electric fan in *S*'s room provided a masking noise. A preliminary interval of 15 min. was allowed for electrode stabilization and apparatus calibration. After this, the four colored stimuli were presented to *S* in a random order to acquaint him with the stimuli. The shock was then adjusted and three sensitization trials administered. This was followed by an adaptation series to all four stimuli presented randomly in blocks of eight. The adaptation series consisted of four presentations without shock of each of the four stimuli, or one presentation of all four with zero GSR, whichever took longer.

The acquisition series involved the presentation of three of the four stimuli (two reinforced, one nonreinforced). Orders of presentation were varied in random blocks of six and the assignment of colors to the reinforcement conditions was rotated systematically from *S* to *S*. Test trials on all four stimuli[4] were interspersed (after the fifth and eighth reinforcements) in the acquisition series, which continued until 10 reinforced trials had been given to two of the stimuli and the other stimulus had been presented 10 times without reinforcement.

The final test situation presented two random blocks of stimuli without reinforcement. At the outset of the study, these postconditioning

[3] On the basis of preliminary experimentation it was found that some form of "task" condition was necessary to assure *S*'s attention to the visual stimulus situation. Of several tried, the anticipation task appeared best adapted to this situation. It did, however, establish a component set during acquisition and would have led to questions by *S* if continued during the test series on compounds. Therefore, *S* was instructed not to predict aloud the stimulus during this latter series. Certain implications of the use of this task variable were evaluated by preliminary experimentation and it was concluded that these instructions did not operate differentially with respect to the conditions of the experiment.

[4] In order to evaluate the influence of the "strange" stimulus during test trials in the acquisition series, this stimulus was withdrawn from those test trials after *S* 18. Subsequent analysis showed the presence of this extra stimulus had no apparent effect upon responses to the other stimuli.

series contained both compounds and individual stimuli randomly interspersed. To reduce the effects of extinction during the long test series, the individual stimuli were omitted from post-conditioning test trials after *S* 13. This made it necessary to employ the last interspersed acquisition test trial (between reinforcements eight and nine) for evaluating the degree of conditioning to components when the entire group was involved, although some comparisons were made employing the smaller subgroup (of 13 *S*s).

The selection of a unit in terms of which to specify the magnitude of the GSR was the first problem posed in analyzing the results. Because the crucial postlearning measurements were spread over many trials without interspersed reinforcements, a great deal of extinction occurred, with accompanying zero-magnitude responses. It became necessary to evaluate the trial-by-trial differences in distribution form (normality), the number of zero responses, and the resultant effects of these factors on measures of variability. Six different transformations of resistance change were evaluated empirically. These included conductance change, logarithm of the conductance change, logarithm of the resistance change, the difference (or change) in the logarithms of resistance (and conductance), the square root of conductance change, and the difference (or change) in the square root of conductance.

The results of this unit check are too lengthy to report here but they may be summarized as follows: (*a*) no transformation led to normality; (*b*) none completely removed the correlation of base and change measures, although some reduced it significantly; (*c*) the distribution of conductance change was markedly affected by extreme scores; (*d*) the log of resistance change gave greatest symmetry in the absence of zero measures, but with increasing numbers of zeros a second mode occurred at the base of the distribution; (*e*) the presence of this "zero mode" systematically influenced group variances—in fact, for some transformations it made the variances roughly proportional to the number of zeros; and (*f*) variance heterogeneity could be reduced effectively by adding an appropriate constant to the scores prior to log or square-root transformation.

Due to the complexity of this situation, *t* and *F* tests of all comparisons were run with the three best transforms: square root of conductance change, log of resistance change, and conductance change. These results agreed closely. Later, individual comparisons were checked by nonparametric (paired replicates) tests. These also agreed with the earlier results. Only the results with the square root of conductance change are presented here.

TABLE 1

GSR* TO DIFFERENT CLASSES OF INDIVIDUAL STIMULI ON LAST ACQUISITION TEST SERIES

Stimulus	*N*	Mean	*SD*
First Reinforced	32	1.29	.71
Second Reinforced	32	1.30	.74
Nonreinforced	32	1.02	.71
Not-presented	18	1.08	.62

* Square root of conductance change.

RESULTS

The extent to which differences in response evocation properties among the four individual stimuli were achieved can be evaluated by examining the magnitudes of response to the various classes of individual stimuli on the last test trial interspersed during acquisition. The means and *SD*s are summarized in Table 1. Tests of the differences by *t* tests of the mean difference show that responses to the reinforced stimuli are significantly greater than to the nonreinforced stimuli in the case of both reinforced stimuli (*t*s are 3.01 and 3.37, with 31 *df*). The intermediate value for the not-presented stimulus is more difficult to evaluate since it was tested with the other stimuli for only a portion of the *S*s. With this subgroup the mean response to the not-presented stimulus lies in an intermediate position yielding *t*s of 2.27, 1.59, and 2.09 for comparisons with the two reinforced and one nonreinforced stimuli, respectively, all with 17 *df*. All of these facts taken together support the conclusion that at least two and possibly three levels of response potential were established to the components as a result of the acquisition series.

The first test of the experimental

TABLE 2

GSR to Combinations (Pairs) of Stimuli ($N = 32$)

Combination	Test 1		Test 2	
	Mean	*SD*	Mean	*SD*
$+_1 +_2$	1.35	.76	1.09	.95
$+_1 -$	.79	.67	.55	.65
$+_2 -$	.71	.75	.59	.71
$+_1 0$	1.03	.80	.89	.72
$+_2 0$	.94	.63	.82	.79
$- 0$	.85	.81	.83	.88

hypothesis consists of a comparison of the average reactions to the combinations or pairs of stimuli. Table 2 presents the average GSRs to these classes of stimuli during the test series. For purposes of description the combination of two reinforced components is given in the table as $(+_1 +_2)$; a reinforced and nonreinforced pair as $(+-)$; a reinforced and not-presented pair as $(+0)$; and a nonreinforced and not-presented pair as (-0). An over-all evaluation of the differences among these conditions is shown in the summary of the analysis of variance in Table 3. It may be concluded that there are some differences among the stimulus pairs as well as a significant extinction effect (difference between the first and second test series). Although the data are not presented in the table, further analysis was made to evaluate whether the differences among pairs were different from one test series to the other. They were not. It will also be noted that there were two stimulus pairs combining reinforced and nonreinforced components and two pairs combining reinforced and not-presented components. These stimulus subclasses were kept intact (not combined) for the analysis of variance.

To evaluate the differences among individual means of experimental classes, each of the post-test series was treated separately as follows. Using the logic of the *t* test of a mean difference of paired scores, a critical mean difference for the 5% and 1% *t* ratios was estimated for each set of data. The mean square for the interaction of experimental treatments and *Ss* was used in estimating the variance of the mean of the distribution of differences between paired scores.

For both test series this critical difference was found to be the same, namely, .28 at the 5% criterion and .38 at the 1% level. An examination of Table 2 leads to the general conclusion that the principal differences are those between the $++$ class and the others; although the differences between $+-$ and $+0$ categories are significant at better than the 5% level in two out of the four most appropriate comparisons. In terms of the original hypothesis it appears safe to conclude that the magnitude of response to a combination of two previously reinforced stimuli is significantly greater than to compounds of stimuli treated differently during the training series. There is also some indication that a compound composed of a reinforced and "strange" stimulus yields a higher magnitude than a reinforced-nonreinforced compound. Further evidence for this fact can be seen by an analysis

TABLE 3

Analysis of Variance

Source	*df*	*MS*	*F*
Combinations	5	2.85	8.38**
Ss	31	3.53	10.38**
Combinations × *Ss*	155	.33	
Extinction	1	2.09	6.15*
Error	191	.34	

* $P = .02$.
** $P < .01$.

of the data which averages the four measures making up the +0 and +− categories for each *S* and compares the group means so obtained. When viewed this way the differences between category means yield *t*s of 2.07 and 3.01 for the first and second posttest series, respectively (each with 31 *df*).

Discussion

The results support conclusively the statement that, for this particular class of stimulus, the response magnitudes to simple combinations are determined by some form of interaction of the response potentials of the components. The situation is most clear when two tendencies to respond are combined, for this pairing yields a larger reaction than any of the other combinations tested. The magnitude of response to a compound of a "neutral" stimulus and a stimulus with a positive reaction potential (+0) appears to occupy an intermediate position between compounds made up of two tendencies to respond (++) and the combination of a tendency to respond and a tendency not to respond (+−). Because the "neutral" stimulus has not occurred during the learning series, it would not be predicted to possess learned response evocation properties acquired in the experimental situation. On the other hand, because it was introduced somewhat unexpectedly in the test series, it may have tended to startle *S* or cause him to be alerted to something new in the experimental situation.

It should be noted that it is not possible to attribute these observed differences entirely to an interaction of response tendencies acquired during response training. It is possible that the presentation of any two "similarly treated" stimuli would elicit a different reaction from *S* than would a pairing of stimuli associated in some way with different experience histories. This cannot be evaluated here since the ++ category is the only pair of this "similarly treated" type provided for.

Another way to evaluate the differences obtained involves applying to these same data the patterning statistic which was proposed by Hull (2). This index of patterning is computed by dividing the response magnitude to the compound by the sum of the response magnitudes to the components. On the basis of the hypotheses posed in the present study, the index would be expected to be largest for the two reinforced stimuli, less for a reinforced and strange stimulus pair, and least for a reinforced and nonreinforced pair. To check this prediction, values for the index were computed from the means of the 13 *S*s who possessed tests of individual stimuli randomly interspersed with the compounds. When the +0 and +− subcategories are combined as described earlier, the indexes for ++, +0, and +− were .75, .50, and .36 respectively. These conform to the order hypothesized, but this fact is difficult to evaluate with so small a sample until more is known of the sampling behavior of this particular index.

Summary

The GSR of 32 human *S*s was conditioned differentially to three classes of colored light stimuli by the operations of (*a*) consistent reinforcement by electric shock, (*b*) consistent nonreinforcement, and (*c*) nonpresentation during training. The magnitudes of response to pairs or compounds of stimuli were then observed and evaluated, with the prediction that response magnitudes to the combinations would be simple resultants of the response potentials of the components.

The response to a compound composed of two reinforced stimuli was found to be significantly greater than the response to any other compound; and the magnitude of reaction to a combination of reinforced and nontrained stimuli was greater than that to the combination of reinforced and nonreinforced stimuli. These relations were observed both for mean response magnitudes to stimulus classes, and for a ratio "patterning index" proposed by Hull.

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A REAPPRAISAL OF THE TRANSFER AND RETROACTION SURFACE

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In 1949 Osgood (6) stated three "empirical laws" governing transfer and retroaction phenomena.[2] He incorporated these laws in a three-dimensional diagram which he called the "transfer and retroaction surface." Both the laws and the surface were meant to account for the effects *on* and *of* interpolated learning in successive learning sessions, taking into account a range of stimuli from "identical" through similar to neutral, and responses ranging from similar through neutral to opposite, and "antagonistic." The diagram representing the transfer and retroaction surface appears in the original article, Osgood's text (8), McGeoch and Irion (5), and in Deese's text on learning (3). It need not, therefore, be reproduced here. In view of the influence of Osgood's text on the thinking of students in the field, it is advisable to determine whether the picture drawn so precisely by Osgood is to be accepted as the solution to the puzzle that he has described as the "similarity paradox in learning."

The laws were based on a review of many experiments in which either stimuli or responses had been varied and one experiment, that of Bruce (2), where both stimuli and responses were varied. According to Osgood, " . . . *there are no exceptions to the above empirical laws*" (6, p. 135). Unfortunately, these are *ad hoc* laws, based on a variety of experiments dealing with both nonsense and meaningful materials, nonsense syllables in series and paired associates, symbolic and word or letter stimuli. In none of the experiments was there a systematic arrangement of variations in the stimulus and response aspects that would neatly fit the theoretical formulations. Osgood, himself, for example, used letters as stimuli which remained identical and varied the meanings of words through a series of steps. Gibson's (4) results were heavily relied upon by Osgood, but Gibson had varied only the stimulus components.

The present experiment was designed to test all of the key points on the transfer and retroaction surface when both stimuli and responses could be varied through all of the stages described by Osgood.

METHOD

Experimental design.—For the purposes of meeting the requirements of the present design, a set of stimuli varying from similar to neutral was needed. This requirement was met by the already tested visual patterns employed by Gibson. These patterns provided two degrees of similarity as well as an "identical" and "neutral" set. Each set comprised 13 visual patterns or diagrams. The response requirements were of the same nature and were met by Osgood's set of word lists which he had established as entitled to the labels "similar," "neutral," "opposed"; and, of course, the original list which could be used as identical. Osgood's "opposite" list was not used because of the possibility that mediating functions might operate to alter the learning.

With sets of stimuli and responses each varied through four stages, including "identical," the present experiment was arranged in the typical retroaction inhibition paradigm with different *Ss* learning different combinations of the stimu-

[1] The writers are grateful to Dr. Charles E. Osgood for a critical reading of the manuscript.

[2] The laws are quoted in the "Discussion" in connection with the present findings.

lus-response variations as interpolated material. All *Ss* learned the same material in original learning and recalled and relearned (if necessary) this material after the interpolated learning.

Fifteen sets of interpolated learning materials were prepared. Each set was learned by a different group of *Ss*. The arrangement of the groups is shown in Table 1, but can be appreciated now by recognizing that three groups of *Ss* learned new material with stimuli identical and responses either similar, neutral, or opposed;[3] that four other groups learned with similar stimuli and the same arrangement of response groups; four more with less similar stimuli, and four others with neutral stimuli and the same response arrangements mentioned above. Group 17 did not learn any interpolated material and served as a control.

Apparatus and procedure.—The basic materials described above were drawn on 3 × 5 in. cards and exposed by means of a device described previously (1) which permitted a separate controlled time for both stimulus and response. In effect *S* saw a stimulus design appear for 2 sec.; then the response word appeared beside the stimulus design for 2 sec. Thirteen such stimulus and response cards made up a series. Cards were shuffled between runs and dropped from the pack when successfully anticipated twice in a row. After learning all of the cards *Ss* rested 2 min. and then learned an interpolated set to the same criterion. Following the interpolated learning, *S* again rested 2 min. and then recalled the original set. If recall was not complete, *S* relearned the unrecalled sequences to the original criterion. The control group rested similarly but filled in the learning time of the experimental *Ss* by reading the *New Yorker* for 8 min. (the average learning time for the interpolated lists).

Subjects.—The *Ss* were 144 college students drawn as volunteers from psychology courses at the University of Buffalo. They were assigned randomly to experimental conditions. Every sixteenth *S* was designated a member of the control group. Subjects who failed to learn the original list in under 15 trials were discarded and replaced. There were five such cases.

[3] Group 1 is an imaginary group It is assumed that continued practice on the *same* materials already learned to a criterion of two perfect recitations could not but result in better learning. Due to the procedure of removing the learned items, the group, if actually run, could be given only two more trials. There is no way in which such a group could be treated for the rest of the interpolated learning without possible interference. It is, therefore, assumed that their recall would be perfect.

Results

The basic data consisted of learning scores for original and interpolated materials, and recall and relearning scores on the original material. Osgood argues that transfer and retroaction are but two sides of the same coin, and the same conclusions would apply to either transfer or retroaction with only a difference of sign. This analysis implies that there should be a strong negative correlation between trials to learn the interpolated material and recall of the original. If this is the case, there is no need to analyze one set of the data. Rho was − .85, which appears sufficiently high to accept Osgood's view. Actually all of the data were analyzed in detail and the results on the interpolated learning do not violate any of the findings from the recall data. For space-saving purposes, then, only recall and relearning data are considered.

The data of consequence to the issues involved appear in Table 1. The original learning was fairly uniform and an analysis of variance revealed no differences of moment among the groups ($F = 1.107$, with 15 and 128 *df*, $P > .20$). The recall scores, on the other hand, provide more interesting variations. Here there were significant differences as shown by an analysis of variance ($F = 5.390$, with 15 and 128 *df*, $P < .001$). After accounting for the differences in initial learning ability by an analysis of covariance, the F for recall was raised to 6.861 (with 15 and 127 *df*).

Observing the rank order of adjusted recall scores (Table 1) shows the immediate importance of the role of identical stimuli (Groups 2, 3 and 4) each of which showed poor recall. Similarly, identical responses provide a cluster of interesting scores.

TABLE 1

MEAN SCORES FOR ORIGINAL LIST, INTERPOLATED LIST, RECALL, AND RELEARNING OF THE ORIGINAL LIST (N = 9 for each condition)

Experimental conditions		Original list		Unadjusted interpolated		Unadjusted recall		Adjusted* recall	Adjusted* recall	Relearning	
Group	Interpolated list†	Trials	*SD*	Trials	*SD*	Words	*SD*	Words	Rank order	Trials	*SD*
1	S_I R_I	—	—	2‡	—	13‡	—	13‡	1	—	—
2	S_I R_S	7.67	2.11	6.89	1.45	6.22	3.99	6.45	17	5.78	2.44
3	S_I R_N	8.11	3.11	6.44	2.22	6.56	1.64	7.00	16	5.11	1.79
4	S_I R_O	7.33	2.58	6.22	1.87	8.33	2.54	8.40	10	5.22	1.69
5	S_S R_I	7.11	2.28	3.44	1.26	12.33	1.05	12.29	2	1.22	1.75
6	S_S R_S	6.11	2.02	6.44	2.11	8.00	2.45	7.48	15	4.78	1.03
7	S_S R_N	6.44	1.50	5.67	1.70	8.33	1.83	7.96	12	4.56	1.07
8	S_S R_O	8.44	3.13	6.44	2.17	7.78	2.25	8.38	11	5.67	1.94
9	S_{S_L} R_I	6.33	1.41	3.78	0.63	12.44	0.50	12.03	3	1.78	1.62
10	S_{S_L} R_S	6.67	2.40	4.89	0.99	8.11	3.21	7.86	13	4.44	1.26
11	S_{S_L} R_N	6.00	1.76	4.67	1.94	9.67	1.76	9.20	8	3.67	0.82
12	S_{S_L} R_O	5.77	1.31	6.00	1.82	8.33	2.36	7.65	14	5.00	2.58
13	S_N R_I	7.22	1.81	5.00	1.56	11.33	1.84	11.34	4	2.89	2.10
14	S_N R_S	8.44	2.45	4.67	0.94	8.44	2.22	9.04	9	4.56	1.50
15	S_N R_N	8.33	3.56	5.89	2.47	9.22	3.01	9.71	7	4.33	3.05
16	S_N R_O	7.33	2.71	5.00	1.36	10.67	1.41	10.74	5	3.00	1.83
17	Control	7.67	2.83	—	—	10.33	2.31	10.56	6	2.67	1.49

* Adjusted after analysis of covariance.
† Subscripts: I—identical; S—similar; S_L—less similar; N—neutral; O—opposed.
‡ Hypothetical values.

Groups 5, 9, and 13 are all high in recall efficiency. A third cluster involving neutral stimuli (Groups 14, 15, and 16) is of intermediate standing.

The relearning data show the same trends. The best relearning is shown by Groups 5, 9, and 13 where responses are identical even though stimuli vary. The poorest relearning, on the other hand, is shown by Groups 2, 3, and 4 where stimuli are identical and responses vary. Groups 8 and 12 where stimuli are similar and responses neutral are also poor in relearning. These results are more or less to be expected. However, when responses are only similar instead of identical, the relearning scores are very poor regardless of the nature of the stimuli (see Groups 2, 6, 10, and 14). Because the relearning and the recall data are strongly correlated (rho = − .90) the subsequent discussion will be restricted to the recall data to simplify exposition.

The meaning of the scores becomes apparent when comparisons are made with Osgood's surface. Because this surface is a theoretical construct, no score values can be assigned directly to the points on the curves. However, certain values can be fitted to the curves when these points are translated into empirical operations. For example, the highest point of the Osgood surface becomes, for purposes of these data, a score of 13 or perfect recall. Beyond this point one can consider Osgood's medial plane as the control group achievement. This is the level of attainment where neither transfer nor retroaction is operating, and this is the operational meaning of the control function. A neutral level can, therefore, be set at the control group score, 10.56. With these values established Osgood's curves as

adapted from his Fig. 4 (**6**, p. 139) can be sketched to simplify the comparison of the present data with the relative positions Osgood's empirical laws require.

As seen in Fig. 1, learning varying responses to neutral stimuli (Groups 13, 14, 15, and 16) results in a pattern that does not deviate significantly at any single point from Osgood's straight-line interpretation. Still the points do not lie in any approximation to a straight line and the difference between Group 13 (identical responses) and Group 14 (similar responses) is significant at the .05 level (t following analysis of covariance). The other points are not significantly different, but the pattern of the initial drop and subsequent rise becomes interesting in the light of the succeeding patterns. Figure 1 also shows the patterns for Groups 1, 2, 3, and 4 (identical stimuli, varying responses). Here the pattern for neutral stimuli is repeated. The differences from the control condition are all significant at the .001 level. Further, the difference between Group 2 and Group 4 is significant at the .01 level and that between Groups 3 and 4 at the .05 level. The differences between Group 2 and Group 3 is not significant. The curve representing the effect of identical stimuli is directly opposite in form to Osgood's prediction. According to Osgood, the pairing of identical stimuli with "opposite" responses should be the worst condition. It is actually the best. Neutral responses should be learned more readily than opposed responses, yet this is significantly not so.

In Fig. 2 the two stages of similarity of stimuli are represented along with Osgood's predicted curves. As in the case of neutral and identical stimuli

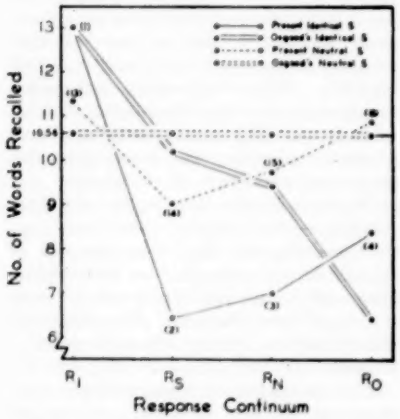

FIG. 1. Recall scores after interpolated learning. A comparison of Osgood's theoretical values with empirical data. The theoretical points were plotted on the basis of a control group performance for the zero effect level and a possible peak score of 13. Recall of original learning material is shown after learning interpolated material consisting of identical or neutral stimuli and identical, similar, neutral, and opposed responses. The numerals represent the experimental groups of Table 1.

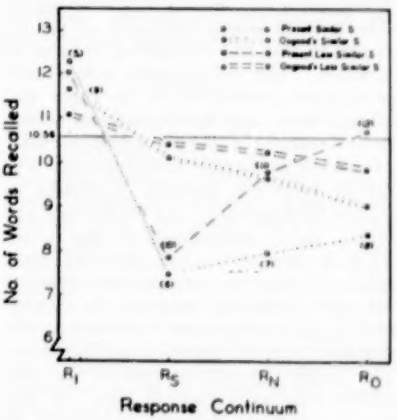

FIG. 2. Recall scores after interpolated learning. (See caption for Fig. 1.) The recall scores after learning interpolated material consisting of stimuli of two levels of similarity and responses ranging from identical through similar and neutral to opposed. The numerals refer to the experimental groups of Table 1.

the data are opposed in trend to Osgood's predictions. The only feature of the data which conforms to Osgood's views is that the more similar stimuli have greater effects than the less similar. In other words, there is a progression of less and less effect as neutrality of stimulus is approached. This is a general confirmation of Gibson's findings with decreasing similarity of stimuli. The Osgood view, with regard to the response continuum does not receive encouragement. Again the point at which similar responses are learned proves the most negative.

Discussion

The transfer and retroaction surface that Osgood (6) evolved was derived from empirical laws, and these empirical laws, in turn, were summaries of facts which were available in 1949. The organization of a large number of studies, many of an apparently divergent nature, into a single conceptual scheme has great pedagogical as well as heuristic value. The present study consisted of an attempt to test this conceptual scheme as a whole. The experimental design permitted an evaluation of the three empirical laws, and by implication of the entire transfer and retroaction surface. It should be noted, however, that the design calls for learning materials in which both stimuli and responses are scaled on a continuum of similarity. Such a continuum has not yet been achieved and the present selection of materials involving diagrams as stimuli and words as responses is obviously not the solution to the scaling problem. The present study represents an empirical test of empirical laws to the extent permitted by the limitations of materials such as were used in the formulation of these laws.

The data collected in the present study offer both support and contradiction for the empirical laws stated by Osgood. Arguing from his transfer and retroaction surface, Osgood states that when interpolated material involves neutral stimuli, there will be no effect on either the learning of the new or the recall of the earlier learning. In general, this is borne out by the present study. When comparisons are made with the recall scores of the control group, no significant differences are found for the four conditions in which neutral stimuli were employed in interpolated learning. There is no evidence for a "straight line of zero effect," however, as one significant difference (at the .05 level) does appear among the scores. This occurs in comparing identical responses with similar responses. There appears to be a different direction of effect when the learner encounters material associated with neutral stimuli. If the responses involved are identical, he will tend to benefit; if similar, to be held back. In Osgood's own common sense terms, this does not appear unreasonable. It is possible, of course, that the stimuli were not truly neutral. Enough experiments on familiarity with materials have been done to justify the assumption that identity of response might well facilitate learning. Similar responses, on the other hand, may not be discriminated adequately, as Gibson suggested was true of similar stimuli. The *S* responds with errors and perhaps with confidence.

On the positive side, again, the data relating to the stimulus continuum support the Osgood view that identity of stimuli has a more serious effect than progressive approaches toward neutrality. Thus, the order of strength of effects is from identity through the two stages of similarity to neutrality.

The contradictory aspects of the data show up in the response continuum, however, and here Osgood appears to be in serious error. Osgood's surface shows a gradually increasing negative effect from the stage of similarity through neutral to opposed responses, whereas the most significant departures from the control base line occur with the similar responses. The similar responses appear to cause the greatest degree of trouble or negative transfer and the effect *decreases*

with less similarity instead of increasing as Osgood would have it do. Actually, the curves appear to conform to the Skaggs-Robinson hypothesis (9) more closely than the Osgood surface. While learning opposed responses does have a negative effect, it is of the least degree and there appears to be no distinction among the stimulus relations involving "opposed" responses. About the same degree of effect is found with identical, similar, and neutral stimuli.

While Osgood is correct in describing the effects that occur with a change in the stimulus continuum, his schema does not hold on the response side. The Skaggs-Robinson hypothesis appears to fit the data quite closely in that negative effects are strong as we depart from response identity and work with similar responses; then, as we approach neutrality, the negative effect lessens and is least with "opposed" responses. The Skaggs-Robinson hypothesis is supported by the same data which negate the Osgood interpretation.

On the basis of the present study, the following generalizations appear justified: Osgood's first empirical law is supported. This law reads: "Where stimuli are varied and responses are functionally identical, positive transfer and retroactive facilitation are obtained, the magnitude of both increasing as similarity among the stimulus members increases" (6, p. 134). Our findings are in harmony with this law with no exceptions of any significance being apparent. It should be noted that this law deals with *stimulus* variations.

Osgood's second empirical law reads: "Where stimuli are functionally identical and responses are varied, negative transfer and retroactive interference are obtained, the magnitude of both decreasing as similarity between the responses increases" (6, p. 135). This law must either be dropped or modified to read "the magnitude of both first increasing and then decreasing as similarity between the responses increases." With this modification, the law becomes, in effect, the Skaggs-Robinson hypothesis.

The third empirical law reads: "When both stimulus and response members are simultaneously varied, negative transfer and retroactive interference are obtained, the magnitude of both increasing as the stimulus similarity increases" (6, p. 135). This law, again concerned with the stimulus continuum, is supported by the current findings.

In view of the current findings, there appears to be sufficient reason to suggest modification of the transfer and retroaction surface, or at least a delay in its acceptance as the final integration of positive and negative transfer. The resolution offered by Osgood appears to work on the stimulus side, but his attempt to resolve what he has termed the "similarity paradox" cannot be accepted. It still remains a paradox that at some point on the scale of similarity a reversal of effect occurs with a positive effect becoming altered into a negative. The Skaggs-Robinson hypothesis, while not explaining this paradox, still remains a reasonable approximation of experimental data. Further and more detailed research on the similarity continuum may reveal factors responsible for the reversal. The present research did not uncover any such factors.

Summary

The influence of similarity of interpolated materials on the retention of original learning was studied. Both stimuli and responses were varied in the interpolated learning through four stages, ranging from identical to neutral and opposed. The experimental design involved a test of the "transfer and retroaction surface" suggested by Osgood to solve the "similariyt paradox." The stimulus continuum was based on Gibson's diagrams and the response continuum came from Osgood's word lists. Within the limitations of these continua, the following conclusions appear justified from the data accumulated on 144 *Ss* divided into 15 experimental and 1 control group:

1. Osgood's first and third empirical laws were confirmed. These laws deal with the stimulus continuum. The second law, dealing with the response continuum, was not confirmed and appears to be in error.

2. Neutral stimuli in interpolated paired associates, in general, have no significant effects on recall of original learning.

3. The correspondence of transfer and retroaction effects as proposed by Osgood is confirmed.

4. The Skaggs-Robinson hypothesis, in general, appears to be a closer integration of the findings than Osgood's surface.

5. The "similarity paradox" in human learning still appears to be a paradox.

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TRANSFER OF TRAINING TO ORTHOGONAL DIMENSIONS [1]

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The importance of the phenomenon of generalization is recognized and its reality widely accepted. Despite its widespread acceptance its bases are still in dispute, a fact which suggests that it is inadequately understood. It has generally been considered a property of the organism, which, although modifiable by species, motivational, mensurational, and dimensional parameters, is not itself a product of learning. In recognition of this fact a number of investigators have attempted to determine *the* generalization gradient for a given situation with ever increasing precision (**4, 6, 9, 14**). According to Hull's system (**5**), the mechanism underlying response generalization is a gradient of excitatory tendencies which is affected principally by the number of trials (**5**) and the range of stimuli within the dimension to which training is given. Excellent discussions of the various viewpoints of stimulus generalization have been presented by Lashley and Wade (**8**), by Razran (**10**), and by Brown, Bilodeau and Baron (**2**), and therefore need not be reviewed here.

In contrast to this position of static generalization is the hypothesis that the range of stimuli in one dimension to which *S* responds can be increased or decreased by training in another dimension. Stating this hypothesis in somewhat more quantitative terms, training to give a unitary response to a wide range of stimuli in one dimension results in heightened responsiveness to a wide range of stimuli in an orthogonal dimension within the same modality; conversely, concentration of training within a narrow range along one dimension results in responsiveness to a narrow range of stimuli in an independent dimension of the same modality. In similar vein, giving a differential response to stimuli in one dimension will sharpen the generalization gradient in another dimension.

The purpose of the present experiment was to determine whether such interdimensional transfer of generalization would take place in a voluntary response to stimuli located at different points in visual space. As Brown, Bilodeau, and Baron (**2**) have demonstrated, clear-cut gradients occur in this domain.

Method

Apparatus.—Our apparatus was patterned after that of Brown, Bilodeau, and Baron (**2**). The major component of the apparatus was a stimulus panel 8 ft. square and painted flat black. This panel was mounted upright in a semidarkened room. Thirteen holes, .25 in. in diameter, were drilled through the board to form a large cross. The distance between adjacent holes was 8° visual angle as determined from *S*'s position. Across each hole was a piece of white translucent paper that could be lighted from behind by a 7-w. bulb. Four tiny red lights arranged in a 6-in. square surrounded the center light.

The reaction (telegraph) key was mounted on the armrest of a standard classroom chair. Each key was connected to a Standard Electric timer and to the mercury switch controlling the stimulus lights. With this instrument *S*'s reaction time could be measured to .01 sec.

Subjects.—The *S*s were 120 undergraduate students at Emory University. None was aware of the purpose of the experiment.

Procedure.—The *S*s were led into the semidarkened room in groups of three or less. They

[1] Supported in part by a grant (MH-589C2) from the National Institute of Mental Health of the National Institutes of Health, Public Health Service.

were seated in chairs so arranged as to minimize deviations from the calculated viewing point. They were also instructed in the use of the telegraph keys. The *E* then read the following instructions: "I want you to look at the four red lights all the time the experiment is going on. I will be behind the board, and when I say 'Ready,' you are to press down on the telegraph key and hold it down until you see a white light. As soon as the white light comes on, release the key and wait until I say, 'Ready,' again. You press down when I say, 'Ready,' and you release when the white light comes on."

These instructions differed from those used by Brown, Bilodeau, and Baron (2), in that their *S*s were instructed to respond only to the center light. We could not duplicate their instructions exactly because of our experimental conditions.

Experimental design.—There were 12 experimental and 12 control groups. The 12 control groups were all trained to respond to the onset of only the center light. Six of these groups were subsequently tested along the horizontal dimension and the remaining six groups were tested along the vertical dimension. The groups differed from each other in terms of the test light presented on the first test trial. In the remaining five test trials responses were tested to the remaining test lights in *S*'s respective dimensions. For all these groups the center light was presented 28 times, with an intertrial interval of approximately 10–15 sec. Starting with Trial 29, one trial in each block of five trials was a test trial, the other four trials involving responses to the center light. The *S* was unable to predict which light would be turned on.

The procedure for the 12 experimental groups was the same as that for the control groups except that the training trials and the trials interpolated between test trials were distributed in a balanced but unpredictable order among all the seven lights in either the vertical or in the horizontal dimension. On the last training trial (Trial 28) the center light was illuminated as in the control groups. Groups trained along the horizontal dimension were tested along the vertical, and vice versa. Again, the six groups of the two sets were identified solely by the light presented on the first test trial.

Results

The latency of response on each trial was noted to .01 sec. for each *S*. The reciprocal of this value was taken and the common logarithm recorded as the prime datum. In the rare instances in which *S* made no response to the test light, a latency of 2 sec. was assumed. Data were analyzed in terms of the speed of response on the first test trial and also in terms of all six test trials. In relation to the theoretical argument, the former index purportedly measures "pure" generalization whereas the latter involves discrimination as well. The latter measure is usually more reliable.

A number of statistical tests were performed to determine whether there were significant differences in gradients among the four radii. In every analysis the null hypothesis could be sustained. For that reason all data were pooled in terms of distance from the center light.

The two panels of Fig. 1 portray the results of the experiment. The top panel denotes the data for all six test trials whereas the lower panel shows the gradient based on only the first test trial. The data are essentially

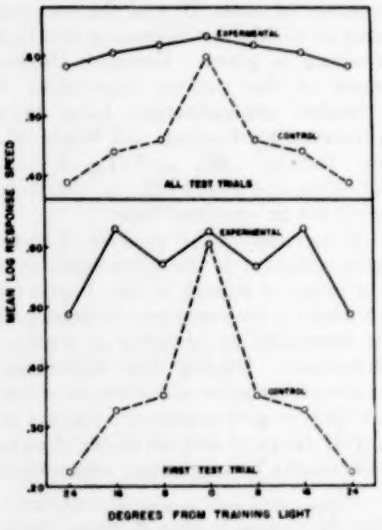

Fig. 1. Generalization of a voluntary response to a light stimulus.

the same in both cases: in general the experimental groups responded faster than the control groups. In addition, the gradients of response are flatter for the experimental groups than for the control groups. Analyses of variance performed on the data for the first test trial and for all test trials revealed highly significant (.001 level) differences between the experimental and the control conditions and a significant interaction of conditions by distance from the center light.

Discussion

A number of routes may be taken in seeking sufficient explanations for the present results. The concept of generalization already has been shown to be modifiable by motivational changes (**1, 12**) and by reinforcement procedures (**5, 7**). Whether or not the current concept of fixed generalization of habit strength or a broader one which permits the operation of training variables should be invoked will depend on many other factors. The finding of Reinhold and Perkins (**11**) that training on an irrelevant discrimination steepened the generalization gradient suggests the operation of such training variables. Tolman's notion of the breadth of the cognitive map (**13**) may also apply here. Interestingly enough, the breadth of the cognitive map has been shown (**3**) to be a function of two of the variables which are known to affect generalization, viz., motivation (**1, 12**) and degree of learning (**5**).

Also, since the training stimuli presented to the experimental group differed markedly among themselves, *S* may have become accustomed to these differences and expected each stimulus to differ from the preceding. There was thus greater similarity between test and training trials in the experimental condition than in the control condition.

Finally, mediating verbal sets or other higher order phenomena so characteristic of human learning may have arisen from the experimental training. These sets presumably develop relatively independently of the particular physical dimension involved. Since these factors are not independently specifiable in the present experiment, assessment of their roles is impossible.

Summary

Groups of *Ss* were trained to respond by releasing a telegraph key whenever any one of seven lights in either the horizontal or the vertical arms of a cross of lights was illuminated in a semidarkened room. These are the experimental groups. For other groups of *Ss* training consisted of responding to only the light at the intersection of the arms of the cross. No other lights were turned on during training. These are the control groups.

Experimental groups trained along the horizontal dimension were tested along the vertical dimension, and those trained along the vertical were tested along the horizontal. Half the control groups were tested along the vertical dimension and half along the horizontal dimension. Response decrement measured in terms of speed of response was greater from center to periphery for the control groups than for the experimental groups whether measured on only the first test trial or on six test trials.

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VERBAL RESPONSE STRENGTH AS A FUNCTION OF CULTURAL FREQUENCY, SCHEDULE OF REINFORCEMENT, AND NUMBER OF TRIALS [1]

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This experiment was designed to study the influence of three variables upon the learning and extinction of verbal responses to verbal stimuli. The variables were (*a*) cultural frequency, or the frequency with which a group gives a word in response to a particular stimulus word, (*b*) schedule of reinforcement, or the percentage of trials that are experimentally reinforced during acquisition training, and (*c*) the number of trials administered during the learning series.

Estes (1) has suggested that latent strength affects the differential susceptibility of words to reinforcement. Because a response of high preexperimental frequency is more likely to be emitted during a training trial, it has a greater probability of obtaining maximal strength sooner than a response of low initial frequency which may require many trials for elicitation. In this experiment, cultural frequency of a response to a given word was chosen as an index of latent strength which could be systematically varied. Schlosberg and Heineman (6) have offered evidence that individual reaction times are inversely correlated with the cultural frequency of a response.

Different percentages of reinforced-nonreinforced trials were studied to determine the relative effects of the schedule of reinforcement. Since both the number of trials and the percentage of reinforcement are necessarily confounded within a single experiment, the two factors were manipulated in a way designed to make possible the statistical separation and identification of interaction effects. The major interest in number of trials as a variable was to test its possible interactions with the other two variables.

Using English words as responses to be learned to specific English stimulus words, the following phenomena were predicted: (*a*) differential strengthening effects from reward to habits initially high or low in the repertoire of the organism, (*b*) increased resistance to extinction following an acquisition schedule of intermittent reinforcement, and (*c*) decreased latency as a function of the number of presentations.

METHOD

Subjects.—Forty-eight sophomores (24 male, 24 female) in elementary psychology classes at the University of Minnesota were the *S*s. None had previously participated in a psychological experiment.

Apparatus.—The *S* viewed the learning materials through a 2½ × ¾-in. aperture centered 7¾ in. from the top of a 19¼ × 19-in. black plywood screen which stood on a table. A framework mounted behind the aperture held the double 3 × 5-in. white cards on which the learning materials were printed. A 115-w. frosted light bulb hung approximately 39 in. above *S*'s head. As each card was placed in the

[1] This article represents a portion of a dissertation submitted to the Graduate School of the University of Minnesota in partial fulfillment of the requirements for the degree of Doctor of Philosophy. The author wishes to express appreciation to her adviser, Dr. Wallace A. Russell.

framework, *E* depressed a reaction key until the correct response was given. The key activated a .01-sec. Standard Electric timer. The time in seconds elapsing from the insertion of the stimulus card until the correct response was emitted and all responses made to each stimulus were recorded throughout the entire experiment.

Design.—The nature of the three variables studied in this experiment led to the selection of Lindquist's "Mixed Design, Type III" (**3**, p. 281) in which all treatments in one classification are administered to each *S* (in this case, number of trials) and this classification with its interactions treated as a within effect. The *S*s are assigned randomly to combinations of the other classifications (here cultural frequency and schedule of reinforcement). These two variables and their interaction are treated as between effects.

Each *S* had 16 presentations of one stimulus, 8 of the second, and 4 of the third. With the aid of a table of random numbers, *S*s were assigned to the 100%, 50%, or 25% schedules of reinforcement, and then to either a high or a low cultural-frequency response for each of the three stimulus words. Thus each *S* learned all associations under a particular schedule of reinforcement but the cultural frequencies of his three designated responses could vary. All randomizations were restricted to maintain a total of 8 *S*s in each of the 18 cells.

The two schedules of partial reinforcement were arranged using a table of random numbers with the restrictions that the first presentation of the stimulus word be reinforced and that one-half (50%) or one-fourth (25%) of the trials be reinforced during the learning series. A trial was defined as the period between the insertion of the stimulus card and the removal of the same card.

Four different packs of stimulus cards representing different orders of the same stimuli were prepared to control possible sequence effects. The *S*s were randomly assigned to the packs.

Learning materials.—The three stimulus words, *hard*, *light*, and *butter*, were selected from the Minnesota Revision of the Kent-Rosanoff norms (**5**) so that the distributions of the frequencies of the response words for each stimulus were similar in form though not, of course, in content. The high-frequency responses to *hard*, *light*, and *butter*, that were reinforced during learning, and the percentages of the norm group (**5**) giving them, were *soft* (67.0%), *dark* (64.2%), and *bread* (63.25%), respectively; the low-frequency responses were *work* (1.59%), *heavy* (1.59%), and *eggs* (1.59%), respectively.

A stimulus word was typed with black capital letters in the center of each card, 1¼ in. from the bottom edge. A supplementary card was stapled to the back of each for additional support. Four packs of 28 cards were prepared, each pack consisting of 16 *hards*, 8 *lights*, and 4 *butters*. Within each pack the words appeared randomly. Since the acquisition time for the three words was approximately the same, the average time interval between trials was longer for *butter* than for *light*; and longer for *light* than for *hard*.

Three lists of 20 words using 10 words that were given in response to each of the stimulus words and 10 words given to other Kent-Rosanoff stimuli, but not to the one in question, were prepared as prompting devices to use when the correct response was not given within 4 min. The appropriate word was included in each list. Use of the prompter cards was required by 15 *S*s, all of whom were learning a low-frequency response.

Learning.—Each *S* received the following instructions: "In this experiment you are to learn the correct word to the words you will see in the window. As soon as a word appears in the window you say the first word you think of. If it's the right one, I'll say, 'Right.' If I don't say anything, you keep saying words the word in the window makes you think of. When another word appears in the window, you begin again giving words. All of the words are common English words and are ones that people often think of when they see these words. Because you have to think of words as soon as you see one in the window, it will be like a guessing game until you learn the right word. The only way for you to find out what the right word is—is to hear me say, 'Right.' Just keep on saying words you think of the way you have been doing. You will not receive shock or any other kind of unusual stimulation during this experiment. Remember, the task is to learn the right word to the word in the window. Let's try one . . . ."

For one trial of "pretraining" the word *cabbage* was presented until *S* had made two responses. Then, regardless of the content of the two responses, *E* said, "Right," and removed the card. The 28 cards of *S*'s pack for learning were then presented successively, each card remaining in the aperture until the correct response had been given on the reinforced trial or until the emission of three words after the correct response in the case of the nonreinforced trials. This latter procedure was used in an attempt to minimize reinforcement received by the change of cards.

Extinction.—Without any interruption or comment after the completion of learning,

TABLE 1

MEANS AND *SD*s OF SQUARE ROOT TRANSFORMATION OF THE NUMBER OF WORDS PER TRIAL TO THE CORRECT RESPONSE DURING LEARNING

% Reinf.	High Cultural Frequency						Low Cultural Frequency					
	16 Trials		8 Trials		4 Trials		16 Trials		8 Trials		4 Trials	
	Mean	*SD*	Mean	*SD*	Mean	*SD*	Mean	*SD*	Mean	*SD*	Mean	*SD*
100%	1.05	.087	1.03	.062	1.03	.614	1.26	.081	1.36	.150	1.75	.334
50%	1.15	.418	1.13	.149	1.18	.836	1.38	.094	1.63	.301	1.94	.554
25%	1.02	.047	1.46	.326	1.15	.292	1.48	.265	1.67	.346	1.90	.642

extinction trials were instituted. A pack of cards containing equal numbers of the three stimulus words in random order were presented in the following manner: the card was inserted, *E* waited until three responses after the originally correct one had been given or for three responses if the originally correct one was not among them before changing cards. At no time did *E* say, "Right," or make any other comment. This procedure was continued until all three words had reached the extinction criterion: three presentations of the stimulus word to which the originally correct response was not given as the first response. The cards with a given stimulus word were omitted from the pack as soon as the criterion was reached for that word. The *S*s were questioned about their understanding of the experiment and dismissed. None evidenced real insight into the experimental variables.

RESULTS

The variable, number of trials, was designed to compare differing numbers of presentations of three stimulus words. Consequently, it was desirable to test for divergence in initial reaction time in order to compare the ease with which responses were given to each of the three words. A simple analysis of variance was applied to the average latency required to emit the first response, correct or incorrect, to each stimulus word for each *S*. Since *F* was less than one, it may be assumed that initial variations were of a chance nature.

Number of words given in learning.—Both the latency in seconds from the insertion of the card to the emission of the correct response and the number of responses per trial were recorded during the learning series. However, both measures yielded the same results, so only one set will be presented in the interests of brevity.[2] To normalize the positive skew of the raw scores, a square-root transformation was employed. Since four different packs were used to present the learning series, simple analyses of variance were computed to test for differences between means of the latencies for each variable on each pack. The differences being nonsignificant, the four lists were combined for further analysis. Application of the L_1 test for homogeneity of variance to the transformed scores indicated that the assumption of homogeneous variances seemed tenable. Table 1 presents the means and *SD*s of the number of words per trial to the correct response during learning.

Following Lindquist's model in the evaluation of the dependent measures, mean squares of the two variables and their interaction to which *S*s were assigned randomly were tested against the residual mean square for between-groups. The residual mean square for within-groups was used to test the

[2] More complete coverage of all the experimental results may be found in the thesis (4).

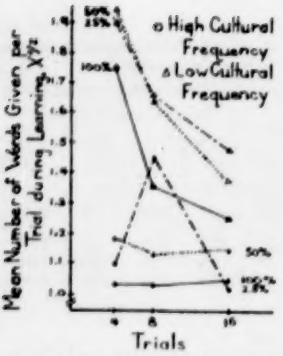

FIG. 1. Means of the number of words given per trial to the correct word during learning (square-root transformation).

variable, number of trials, and its interactions since each *S* took every one of the conditions in this classification. These analyses, shown in Table 2, indicated that the average number of words given per trial during learning was less for the high-frequency responses than for the low; responses learned under a schedule of partial reinforcement were preceded by significantly more incorrect responses than those receiving continuous reinforcement. Generally, fewer incorrect responses were given when 16 trials were employed than with either 8 or 4 trials. The interaction between number of trials and cultural frequency reached the .05 level, $F = 3.73$ with 2 and 84 *df*. A comparison of the means shown in Table 1 and Fig. 1 suggests that the responses preceding the correct response decreased as the number of trials increased when the correct response was of low cultural frequency but not when the correct response was of high frequency.

Extinction trials.—The total length of time in seconds elapsing from the beginning of extinction until the word reached the extinction criterion as well as the number of trials required for the word to reach the criterion were recorded. Only the latter will be reported since both measures gave the same results. Again, data from the nonsignificantly different packs were combined. Application of the L_1 test for homogeneity of variance indicated that the assumption of homogeneity was tenable. The means and *SD*s are presented in Table 3.

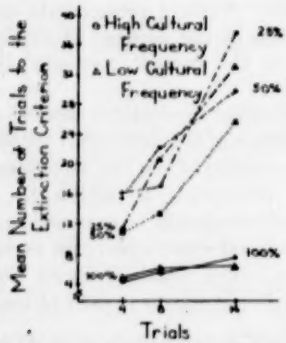

FIG. 2. Mean number of trials to extinction.

TABLE 2

ANALYSIS OF VARIANCE OF DATA IN TABLE 1

Source	*df*	*MS*	*F*
Between *Ss*	47		
Cultural frequency (F)	1	7.66	81.83***
Reinforcement (R)	2	.50	5.39**
F × R	2	.02	—
$Error_{(b)}$	42	.09	
Within *Ss*	96		
Number of trials (N)	2	.91	4.74*
N × F	2	.72	3.73*
N × R	4	.10	—
N × F × R	4	.08	—
$Error_{(w)}$	84	.19	
Total	143		

* Significant at the 5% level.
** Significant at the 1% level.
*** Significant at the .1% level.

TABLE 3

MEANS AND *SD*s OF THE NUMBER OF TRIALS TO EXTINCTION

% Reinf.	High Cultural Frequency						Low Cultural Frequency					
	16 Trials		8 Trials		4 Trials		16 Trials		8 Trials		4 Trials	
	Mean	*SD*	Mean	*SD*	Mean	*SD*	Mean	*SD*	Mean	*SD*	Mean	*SD*
100%	7.75	2.73	5.38	0.48	4.38	1.11	6.50	2.00	6.25	1.79	5.12	2.03
50%	30.00	26.56	22.25	7.92	15.75	7.74	25.88	18.33	13.62	5.63	10.75	7.27
25%	37.75	18.50	17.25	11.69	16.50	11.84	33.25	17.18	20.62	10.21	11.00	7.21

Table 4 gives the analysis of variance for the number of trials to extinction. A greater number of trials was required for extinction when learning trials had been presented under a schedule of partial reinforcement as compared with continuous reinforcement. Sixteen learning trials produced greater resistance to extinction than either 8 or 4 learning trials. The variance ratio for cultural frequency was less than one. The one significant interaction, number of trials and schedule of reinforcement, seems attributable to data contributed by 16 trials and 25% reinforcement. Inspection of Table 3 and Fig. 2 suggests that the additional trials provided for the 16-trial group may have allowed more opportunity for the lowest percentage of reinforcement to become effective.

DISCUSSION

The results obtained in both learning and extinction correspond closely with the predictions. The number of words emitted prior to the correct response decreased in learning. Learning and extinction were slower with a partial reinforcement schedule during acquisition than with a schedule of continuous reinforcement. In general, responses freely associated with high cultural frequency to a particular stimulus word were learned more quickly to that word than were responses with low cultural frequency. However, only the low index responses showed a significant decrease in prior words. The variable, cultural frequency, did not exhibit a reliable influence during extinction.

The variable, number of trials, was in this experiment confounded with the average interval of time between presentations of a particular stimulus. Interpretation of the results must take into account the possible effect of this second variable. Since retention experiments (2) show recall to be directly related to the spacing of learning trials in most situations, the distribution of practice factor should favor the response occurring less frequently. The differences found in the present study would

TABLE 4

ANALYSIS OF VARIANCE OF THE NUMBER OF TRIALS TO EXTINCTION

Source	*df*	*MS*	*F*
Between *Ss*	47		
Cultural frequency (F)	1	115.56	—
Reinforcement (R)	2	3667.11	27.34**
F × R	2	36.58	—
$Error_{(b)}$	42	134.14	
Within *Ss*	96		
Number of trials (N)	2	1696.80	12.35**
N × F	2	21.02	—
N × R	4	427.69	3.11*
N × F × R	4	120.54	
$Error_{(w)}$	84	137.45	
Total	143		

* Significant at the 1% level.
** Significant at the .1% level.

be expected to be greater in the same direction with control of the distribution of practice.

It is possible that negative transfer may have been present so that the interpolated learning of the other two associations between the trials on *butter* had an adverse effect upon retention. Lack of a control group without the interspersed associations prohibits judgment on this factor. Too, the additional presentations afforded by 8 and 16 trials may have provided opportunity for overlearning which increased resistance to extinction. Such an interpretation is supported by the significant interaction which indicated that 25% reinforcement was more effective as shown by greater resistance to extinction when 16 trials were given during the learning series.

The results indicated that verbal responses acquired to verbal stimuli using verbal reinforcement in an operant conditioning arrangement appear to reflect experimental manipulations in a consistent, systematic manner.

Summary

To evaluate the effects of number of trials, cultural frequency, and schedule of reinforcement upon learning and extinction of verbal responses an 18-cell design was used with three treatments for the schedule of reinforcement (100%, 50%, 25%), three for the number of trials (16, 8, 4), and two for cultural frequency (high, low). Stimuli were three words selected from the Minnesota revision of the Kent-Rosanoff norms with approximately equal response distributions. The *S*s learned the response indicated by the prior randomization to the stimulus words presented through an aperture and were reinforced verbally. Immediately following training, extinction was instituted.

Analyses of variance indicated that high cultural-frequency responses were learned with fewer preceding responses than low frequency responses but no differential effect was apparent during extinction. Responses learned under a schedule of continuous reinforcement showed fewer incorrect responses and required fewer trials to reach the extinction criterion than those under partial reinforcement. The number of trials was inversely related to the incorrect responses and directly related to the trials to extinction.

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PREDICTION OF CRITICAL EVENTS IN CONTEXTS OF DIFFERENT NUMBERS OF ALTERNATIVE EVENTS[1]

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This study was designed to determine the frequency with which a critical event, E_o, would be predicted as a function of the relative frequency of occurrence of that event and the number of alternative events. Humphreys (**5**), Grant and associates (**3, 4**), Detambel (**1**), and Estes and Straughan (**2**) have investigated group predictions of particular events with single alternative events using "verbal conditioning" techniques. In these studies it was found that the percentages of positive responses emitted by *S*s tended to asymptote at levels near the relative frequency of occurrence of the particular event.

In the present experiment *S*s were instructed to predict the occurrence of E_o within a context of three different numbers of possible alternative events, A_1, A_3, A_5. Since the a priori probability of occurrence of any of the events according to the logical principle of indifference or insufficient reason is the reciprocal of the total number of possible events, the actual frequency of occurrence of E_o was proportionately greater than chance as A_i increased with a fixed $P(E_o)$. Thus, it was hypothesized that as the number of alternative events, A_i, changed, *S*'s perception of the relative occurrence of E_o would change. Specifically, as A_i increased, it was hypothesized that *S* would perceive the occurrences of E_o as more frequent.

[1] This research was carried out in the Laboratory of Aviation Psychology and was supported in part by the United States Air Force under Contract No. AF 33(616)-43 with The Ohio State University Research Foundation, monitored by the Aero Medical Laboratory. It was presented at the 1955 meeting of the Midwestern Psychological Association. Permission is granted for reproduction, publication, use, and disposal in whole or in part by or for the United States Government.

[2] The writer expresses appreciation to his colleagues in the Laboratory of Aviation Psychology and to the Director, Paul M. Fitts, for their critical readings of the manuscript.

METHOD

Apparatus.—The apparatus was similar in principle to that used by Humphreys and by Grant. The display consisted of a warning light and either two, four, or six event lights placed side by side on a 24-in. × 36-in. vertical panel. The relative frequencies of occurrence of the different events (light flashes) were controlled by *E* from a panel behind the display.

Subjects.—The *S*s were 126 volunteers from elementary psychology classes at The Ohio State University. They were assigned randomly in nine groups of 14 to one of the nine treatment combinations.

Procedure.—The experimental design was an orthogonal arrangement of two variables each at three levels. One variable was the probability of occurrence of E_o, either $\frac{1}{5}$, $\frac{1}{3}$, or $\frac{1}{2}$. The second variable was the number of alternative events, A_i, either 1, 3, or 5. This design, with 14 replications, permits the use of analysis of variance techniques for evaluation of each of the two independent variables and their interaction.

All groups were instructed to predict the occurrence of the leftmost light, E_o, on successive trials by making a plus sign on a sheet of paper for an "on" prediction and a zero for an "off" prediction. Each group was given a series of 120 trials made up of a warning signal and a stimulus event. The warning signal preceded the occurrence of a stimulus event by approximately 5 sec. and then both remained "on" together for 2 sec. The *S*s' predictions were made during the 5-sec. warning period. The intertrial interval was 9 sec.

Trials were randomly arranged within 10 successive blocks of 12 trials according to the assigned relative frequencies. Occurrences of alternative events were equalized as nearly as possible. For example, with $P(E_o) = \frac{1}{3}$ and three alternative events, the 60 occurrences of

alternative events were evenly divided among E_1, E_2, and E_3.

Results

Figure 1 is made up of three separate plots of the percentage of positive (plus) responses as a function of successive 12-trial blocks. Each subfigure in Fig. 1 presents the data for each level of $P(E_o)$. The parameters for the separate curves in the subfigures are the numbers of alternative events, A_1, A_3, and A_5.

After 120 trials, the rate of emission of positive responses is near 50% for the $P(E_o) = \frac{1}{2}$ groups and, if anything, slightly higher than 25% and $16\frac{2}{3}$% for the $P(E_o) = \frac{1}{4}$ and $\frac{1}{6}$ groups, respectively. The trends in the two sets of curves for the $\frac{1}{2}$ and $\frac{1}{4}$ groups are similar to those of Grant, Hake, and Hornseth (**3**), who used the same P levels but with a single alternative event. The curves for the $\frac{1}{6}$ groups represent an extension of the earlier work.

The number of alternative events appears to offer little basis for differentiation of the curves in the subfigures. If we consider *S*s' responses to the task as if it were a two-choice situation, then the data agree closely with the formulations of Estes (**2**) and of Detambel (**1**). Predictions in both cases specify asymptotes at levels equal to the respective levels of $P(E_o)$.

Table 1 summarizes the analysis of variance of the percentage of positive responses over all trials for all *S*s. The F ratio of less than unity for number of alternatives shows the relative unimportance of this variable. The effect of $P(E_o)$, however, is highly significant ($P < .001$). The interaction, like that for number of alternatives, gives an F ratio less than unity.

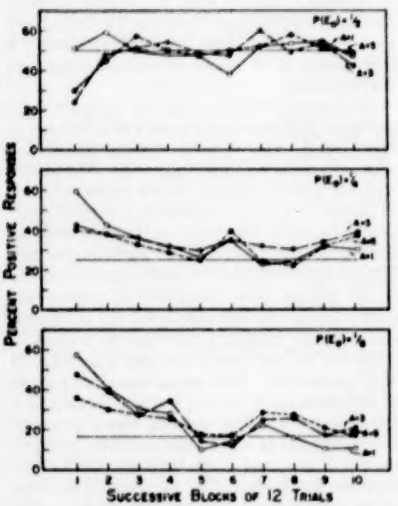

Fig. 1. Percentage of positive responses for the three sets of groups: $P(E_o) = \frac{1}{2}$, $A = 1$, 3, and 5; $P(E_o) = \frac{1}{4}$, $A = 1$, 3, and 5; and $P(E_o) = \frac{1}{6}$, $A = 1$, 3, and 5. Each block of 12 trials contains either 6, 3, or 2 occurrences of E_o with the remaining 6, 9, or 10 trials evenly divided among the As.

Discussion

Of additional interest are the actual frequencies of correct predictions. It can be shown simply that if $P(E_o) < .50$ and if the occurrence of E_o is unsystematic in that the exact order of occurrence is undetected by *S*, then the maximum number of "hits" is obtained when the number of positive responses,

TABLE 1

Summary of Analysis of Variance on Total Positive Responses

Source of Variation	*df*	*MS*	*F*
Between probabilities (P)	2	8903.20	117.67*
Between alternatives (A)	2	37.56	—
Interaction ($P \times A$)	4	37.15	—
Replication (Error)	117	75.66	

* $p < .001$.

TABLE 2

COMPARISON OF MATHEMATICALLY EXPECTED CORRECT RESPONSES AND OBTAINED CORRECT RESPONSES

Measure	Trials 1–120: $P(E_e)$			Trials 61–120: $P(E_e)$		
	⅛	⅓	½	⅛	⅓	½
% positive responses	49	34	25	51	31	19
% correct	50	63	67	49	66	71
Expected % correct	50	58	67	50	60	71

P_r, is zero. Similarly, when $P(E_e) > .50$, best behavior by S is to make $P_r = 1$. When $P(E_e) = .50$ the proportions of positive and negative responses is unimportant. In the latter case no matter what proportions are used by S, the expected proportion of hits will be equal to .50.

If S behaves in some fashion other than that which could be called best strategy, the expected number of hits is calculated with the equation originally stated by Grant (3).

$$P_h = 1 - P_i - P_r + 2P_iP_r \quad (1)$$

where P_h is the expected proportion of hits, P_i is the proportion of positive trials, and P_r is the proportion of positive responses.

Calculation of the expected number of hits with Formulation 1 assumes statistical independence of the stimulus and response sequences. This restriction does not imply that the rate of emission of P_r's by S is not influenced by P_i, but rather that S is not able to predict with certainty the outcome of any one particular trial. In other words, the stimulus sequence should be random. Of course, mathematically, the opposite would also be sufficient—that the sequence of P_rs be random. But in practice it would be difficult to find S responding in a random fashion if he could find a regular stimulus pattern.

To evaluate the random behavior of S with respect to the stimulus sequence, the data from all 120 trials and also the data for only the last 60 trials were scored according to number of *correct* responses. These data are summarized in Table 2.

The expected percentage of correct responses is calculated from Equation 1. The values actually obtained for substitution into this equation are given in the first line in each half of Table 2. No differentiation is made between the three numbers of alternatives since the numbers of positive responses and correct responses are almost identical for A_1, A_3, and A_5.

Table 2 lends powerful support to a statement that the stimulus sequence was "good and random." If S had detected a patterning in the stimulus sequence, then the percentage of correct responses would have been greater than that expected by chance on the basis of the empirical P values used in Equation 1.

The results of the last 60 trials are included separately in order to observe S's behavior after it had stabilized at a fairly constant rate of emission of positive responses.

SUMMARY

Predictions of the occurrence of a critical event were studied as a function of the relative occurrence of that event and the number of alternative events. The critical event was a short flash of a particular light; alternative events were flashes of similar lights. Nine groups of 14 *S*s each were run in an orthogonal design with three levels of relative occurrence of the critical event, ⅛, ⅓, ½, and three levels of alternative events, 1, 3, 5. Ten blocks of 12 trials were used with random arrangements of event occurrences within each block.

The rate of emission of positive responses is significantly influenced by the proportion of occurrences of the critical event. However, the number of alternative events appears to have no effect on *S*s' performance. This lack of effect is consistent at all three probability levels.

The results at the ⅓ and ½ levels corroborate the work of Humphreys and of Grant. Results at ⅛ offer an extension of previous work.

It is concluded that under instructions to classify events simply into critical and noncritical categories, *S*s' behavior is not significantly influenced by the number of noncritical possibilities.

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EFFECT OF PUNISHMENT ON VISUAL DISCRIMINATION LEARNING[1]

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The paradoxical, facilitating effect on learning which results when rewarded responses in a visual discrimination problem are followed by shock has been studied extensively by Muenzinger (**4, 5, 6, 7, 8, 9**) and others (**1, 2, 3, 10**). Two theories, one employing a cognitive-perceptual principle and the other an anxiety reduction hypothesis, have been advanced to explain this phenomenon.

The perceptual theory, supported by Muenzinger, assumes that the shock-induced behavior of pausing at the choice point increases an animal's sensitivity to the cues to be discriminated and thus hastens learning. Two of his studies (**7, 8**) are confirmatory of the theory. In the first, an enforced pause at the point of choice, effected by means of glass doors, increased learning efficiency as much as did shock after the choice point. Similar pause behavior and learning facilitation resulted when animals were made to jump a gap in the maze after the choice point. Unexplained by the theory are the results of Drew's study (**1**) in which animals were shocked in the goal box. Although shock was so removed from the choice point as to preclude inhibitory pause behavior, it nevertheless produced the same improved learning as was found in the Muenzinger experiments.

The anxiety-reduction view, proposed by Mowrer (**3**), assumes that cues associated with shock, such as those from the positive alley, become acquired drive stimuli which induce a drive state termed anxiety. A response which removes these conditioned cues reduces anxiety and strengthens the connection between the cue and the escape response by the principle of reinforcement. This theory attributes the facilitative effect of shock, found in the Drew and Muenzinger studies, to the use of correction training in which animals have to retrace after entering the wrong alley. This required correction permitted only correct alley responses to result in escape from the acquired drive stimuli. Consequently, the correct response obtained the additional reinforcement of anxiety reduction and was more quickly acquired.

In a noncorrection situation, where *S* is not required to retrace after entering the wrong alley, the theory predicts no learning acceleration because an incorrect as well as a correct response permanently removes *S* from the acquired drive stimuli. This prediction was substantiated by Wischner's study (**10**) in which shock for correct responses, under noncorrection training, did not improve learning.

In response to Wischner's study Muenzinger (**9**) has recently demonstrated that the facilitative effect can be obtained with noncorrection training if animals are adapted to shock in pretraining. However, the reason shock-adaptation (which decreases the tendency of animals to

[1] This article is based upon a Ph.D. dissertation submitted to the Graduate School, University of Connecticut. The author is indebted to Drs. W. A. Bousfield, A. M. Liberman, and D. Zeaman for their advice and assistance in carrying out the research.

slow down at the choice point) increases the facilitating effect of shock is not adequately explained by the perceptual theory.

Studies of the facilitative effect of shock, using noncorrection training, do not give unequivocal support to either theory. The two experiments to be described provide additional tests of the two theories.

Experiment I

Experiment I tests the effect on visual discrimination learning of shocking both right and wrong responses in a noncorrection situation. Although the perceptual and anxiety reduction theories yield diverse predictions on this question, there has not been an adequate test of this difference.[2] Muenzinger (**5**) has shown that shocking both right and wrong responses accelerates learning in a correction situation and his perceptual theory predicts the same acceleration with noncorrection training. The anxiety reduction theory allows no improvement in learning under these conditions because right and wrong responses are equally reinforced by anxiety reduction.

Method

Subjects.—The *Ss* were 27 (17 female and 10 male) albino rats approximately 90 days old at the beginning of the experiment. Sixteen of these *Ss* comprised the control group which received no shock. The *Ss* shocked for both correct and incorrect responses were run immediately subsequent to the control group. However, only 11 *Ss* were available for this group. The *Ss* in both groups were from the same colony and strain. The ratio of males to females was about the same in the two groups.

Apparatus.—The apparatus was a single unit T-maze painted a dull black with sides 6 in. high. A single continuous grid covered the floor of the stem and choice-point area. There were three separate grids in each arm of the maze, but only the grid located midway between the choice point and the goal box was activated during the experiment. All grids consisted of 14 ¼-in. copper rods, spaced ½ in. apart, and mounted 1 in. above the maze floor.

The discriminanda were white movable boards that covered the alley walls (but not the goal-box walls) and half the end wall at the choice point. The boards were changed from side to side in randomizing the positional presentation of the positive and negative cues.

The source of the DC shock administered to the *Ss* was a 6SJ7 vacuum tube with a plate voltage of 650 v. The magnitude of the current was controlled by a variable cathode resistor. Variations in the bodily resistance of *Ss* in series with the circuit employed produced negligible variations in the current.

Procedure.—Prior to training all *Ss* were given seven days of habituation to a 24-hr. feeding schedule. They were allowed to eat for 20 min. from the experimental food cups at the time of day they were to run in the pretraining and learning periods. Throughout the experiment the food was wet mash of Purina Laboratory Chow. At the end of habituation each *S* was eating 8 gm. of food in the feeding period.

All *Ss* were pretrained to a criterion of running to either side of the maze in 3 sec. on three successive trials. They were given 10 pretraining trials per day until the criterion was reached. Both goal boxes contained food, and turns were forced, when necessary, to minimize position preferences.

As soon as *S* reached the response criterion set up for pretraining, it was put on the problem of learning the black-white discrimination. At the beginning of each day's trials *Ss* were under a 21–23 hr. hunger drive. The intertrial interval varied between 8 and 20 min. with a median interval of 12 min.

The training was white positive. The sequence of turns was LRLRLLRRLR for the odd days and RLLRLRRLRL for the even days. The *Ss* were given 10 trials per day until they reached a learning criterion of 10 successive correct responses in a single experimental session.

The noncorrection method was used with both the nonshocked control *Ss* and *Ss* shocked for both right and wrong responses. If *S* made the correct response, it was allowed to eat for 5 sec.; on incorrect responses *S* was left in the goal box for 5 sec. before removal. Guillotine-

[2] A study by Freeburne and Taylor (**2**) indicated that shock for both right and wrong responses facilitates learning in a noncorrection situation. However, their learning problem was so difficult (four of 10 control *Ss* and two of 10 experimental *Ss* failed to reach criterion after 500 trials) that shock may have improved learning by decreasing the tendency toward position habits in the experimental *Ss*.

TABLE 1

MEAN TRIAL AND ERROR SCORES FOR THE CONTROL AND SHOCK-RIGHT-WRONG GROUPS

Measure	Control (N = 16)		Shock-Right-Wrong (N = 11)		t
	Mean	*SD*	Mean	*SD*	
Trials	91.25	25.75	100.90	24.12	.919
Errors	37.19	10.61	40.45	9.77	.498

type doors prevented *Ss* from retracing after making the turn at the choice point.

Shock was administered after the choice point only. The intensity of shock was 75 microamperes on the first 10 trials, 100 microamperes on the next 10, and 150 microamperes for all the remaining trials.

Results

Learning scores for the shock-right-wrong and control groups are compared in Table 1. The differences between the groups in terms of both trials and errors are small and not significant.

The results of Exp. II show that the intensity of shock used in this experiment was sufficient to produce a facilitating effect under other conditions. Consequently, these data contradict the prediction of the perceptual theory and support that of the anxiety reduction view.

EXPERIMENT II

In Exp. II the anxiety reduction and perceptual theories were again tested on a visual discrimination problem. Correct responses only were followed by shock, and the number of trials before the introduction of shock was varied. Three experimental groups were employed: a Shock-0, Shock-15, and Shock-25 group, the numbers referring to the number of trials preceding the introduction of shock.

The facilitative effect of shock cannot take place in a noncorrection situation according to the anxiety reduction theory. The perceptual theory requires faster learning as the number of shock-free trials decreases. The sooner shock is introduced the sooner it can facilitate learning.

Method

Subjects.—The *Ss* were 33 (21 female and 12 male) albino rats approximately 90 days old at the beginning of the experiment. There were 11 *Ss* in each experimental group with the ratio of males to females the same in all three groups. Since the control *Ss* of Exp. I were from the same colony and strain and of comparable size and age as the *Ss* in Exp. II, they were used as the control group for Exp. II.

Apparatus and procedure.—The apparatus, pretraining, and learning problem were the same as in Exp. I. Shock was given for correct responses only, however, and was at full strength (150 microamperes) whenever administered. Shock was introduced on the first correct response for the Shock-0 group, on the first correct response after 15 shock-free trials for the Shock-15 group, and on the first correct response after 25 shock-free trials for the Shock-25 group.

Results

The performance of the control and three shock-right groups is compared in Table 2. A simple analysis of variance on these data revealed group differences significant at the .02 level for errors and the .05 level for trials. Among the experime. tal groups the speed of learning appears to be an increasing function of the number of initial shock-free trials. The Shock-25 group was significantly superior to the Shock-0 group for both trials ($t = 3.05$, $P < .01$) and errors ($t = 3.01$, $P < .01$). The Shock-15 group displayed a smaller but significant superiority to the Shock-0 group for both trials ($t = 1.79$, $P < .05$) and errors ($t = 2.08$, $P < .05$). The Shock-25 group required significantly fewer trials ($t = 2.29$, $P < .05$) to criterion than the control group; the difference between these groups on

TABLE 2

MEAN TRIAL AND ERROR SCORES FOR THE CONTROL AND THREE EXPERIMENTAL GROUPS

Measure	Control (N = 16)		Shock-0 (N = 11)		Shock-15 (N = 11)		Shock-25 (N = 11)	
	Mean	*SD*	Mean	*SD*	Mean	*SD*	Mean	*SD*
Trials	91.25	25.75	102.00	25.17	82.73	23.97	69.09	24.12
Errors	37.19	10.61	46.30	11.01	36.73	9.20	32.45	10.79

the error measure was not significant. The Shock-0 group had significantly more errors ($t = 2.15$, $P < .05$) than the control group, but the difference in trials to criterion for these groups was not significant.

Animals in the experimental group displayed a marked decrement in running speed when shock was introduced. It is noteworthy that the Shock-25 group needed only 55 trials to regain its preshock running speed level, whereas the Shock-0 group could not achieve this level after 130 trials. The Shock-15 group required 90 trials to recover its preshock level of running speed.

DISCUSSION

Neither of the theories tested adequately explains all the data of the two experiments described. The perceptual theory is most directly contradicted by the failure of shock-right-wrong training to facilitate learning. The anxiety reduction view does not allow for the increased learning speed with shock-right training in a noncorrection situation.

It is possible that the anxiety reduction theory is consistent with the occurrence of a facilitating effect in a noncorrection situation if some additional assumptions are considered. It was observed that animals made characteristic jump responses, similar to those reported by Wischner (**10**), in negotiating the shock grid. It is assumed that during shock-right training fractional components of these responses occurred at the choice point whenever the animal approached the positive alley. A further postulation is that the proprioceptive stimuli from the jump responses, and consequently the anticipatory components, become acquired drive stimuli and secondary reinforcing stimuli since they are paired with both shock and food.

Since shock is a strongly noxious stimulus, the acquired drive properties of these proprioceptive stimuli should be correspondingly high and minimize the effect of secondary reinforcement. However, if we assume that running time is a measure of the noxious capacity of shock, a point is reached in the acquisition process when the noxiousness of shock is greatly reduced. In this situation the proprioceptive stimuli from anticipatory jump responses may act primarily as a secondary reinforcement for the correct response. This additional reward may account for the marked increase in learning speed found in the latter part of the acquisition process of shock-right trained animals in the Muenzinger, Wischner, and present studies. In the Drew (**1**) experiment where animals made specific motor responses to shock through the food reward and in the Muenzinger (**8**) experiment where animals jumped a gap in the correct alley, the conditions required by this explanation are present. When shock-right-wrong training is employed, the proprioceptive consequences of both correct and incorrect responses are the same, explaining the absence of the facilitative effect in this situation.

The assumption of running time as a measure of the noxiousness of shock is substantiated by the fact that running

speed was not effected by changes in the strength of the correct response, since animals were at or near their asymptote of running speed at the end of pretraining. Running time and presumably the noxiousness of shock are a decreasing function of the number of shock-free trials. The reason for this relationship, the opposite of adaptation, remains a question.

Summary

To provide experimental tests of two theoretical interpretations of the facilitating effect of shocking correct responses in visual discrimination learning, a control and four experimental groups were trained on a black-white discrimination, under noncorrection conditions in a single-unit T-maze. One experimental group was shocked after the choice point for both right and wrong responses. In three experimental groups with 0, 15, and 25 initial shock-free trials, respectively, shock followed correct responses only.

1. The differences between the learning scores of the shock-right-wrong group and the nonshocked control group were small and not significant.

2. Among the Shock-0, Shock-15, and Shock-25 groups speed of acquisition was an increasing function of the number of initial shock-free trials.

3. The control group learned slower than the Shock-15 and Shock-25 group but faster than the Shock-0 group.

4. It was concluded that an anxiety reduction theory, with additional assumptions, was consistent with these experimental results.

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THE ASSOCIATIVE FACTOR IN EYELID CONDITIONING [1,2]

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A previous study (**2**) provided evidence for the existence of two independently manipulable processes in eyelid conditioning. One of these is an associative, or learning, factor which depends upon paired presentations of the CS and UCS; the other is a performance factor, probably a drive, which is acquired with presentations of the UCS, even if the CS is omitted. The experiment which demonstrated the independent functioning of these two processes was one in which *S* received a series of stimulations with the UCS alone, after 20 conditioning trials in which the CS and UCS were paired at a .5-sec. interval. A comparison of the performance of this group during a series of subsequent conditioning and experimental extinction trials with that of a control group revealed that the omission of the CS on as many as 20 trials had no detrimental effect upon the progress of conditioning. These results suggest that the associations formed in eyelid conditioning develop very rapidly, and that the progress of learning appearing in most eyelid conditioning curves reflects mainly the development of the acquired drive factor.

This paper reports two experiments which investigate the development of these associations during the early conditioning trials, following the procedures employed in the previous study. In each experiment different groups of *S*s received treatments designed to produce different strengths of association, followed by a series of trials with the UCS alone. In Exp. I the differential treatment consisted of giving different numbers of initial CS-UCS *conditioning trials*. In Exp. II the independent variable was the number of CRs allowed to occur before the UCS trials. In the two experiments, respectively, resistance to extinction and performance in a series of conditioning trials following the UCS trials provided measures of the strength of the associations.

[1] Financial support for this study was provided by a grant from the National Science Foundation.

[2] A briefer version of this study was presented at the 1955 meetings of the American Psychological Association.

[3] The junior author is now an NSF fellow at Yale University.

EXPERIMENT I

Method

The apparatus, source of *S*s, and general procedure were the same in both experiments. Hence a general description is given here and additional details for Exp. II will be supplied later.

Apparatus.—The apparatus was a modification of that employed in the previous study (**2**). The CS was a light of .25-sec. duration; the UCS was an air puff provided by the fall of a 90-mm. column of mercury in a manometer, magnetically released to the right eye. A synchronous motor controlled the interstimulus (.5 sec.) and intertrial (15 sec.) intervals used in the present study. A very light false eyelash of aluminum foil was attached to *S*'s right eyelid. An eyeblink of approximately .075 in. or more activated a photoelectrically controlled electronic relay and was signaled on a panel of lights.

For these experiments, the apparatus was moved from its previous location to an air-conditioned room which was quieter and more comfortable. A new booth, constructed of plywood and lined with layers of wallboard and acoustic Celotex, served to eliminate most external noises. Finally, the CS was reduced in size and intensity. It was a very dim (.03 mL.) white light, .25 in. in diameter, 20 in. directly in front of *S*. The major effect of these modifi-

cations was to reduce the number of responses obtained in preliminary test trials with the CS alone. In the previous experiments, *Ss* who gave more than 4 responses in a series of 10 such trials were either discarded or given additional CS trials to adapt them. In the two experiments reported here, the maximum number of responses obtained in the test trial series was 4. No *S* was discarded on the basis of the previous criterion.

The only other important modification was the addition of a Standard Electric timer to measure response latency. Although there is no evidence that our previous data contained unlearned or voluntary responses, the latency measures provide an additional check. For similar purposes, a group of 5 *Ss* was run under instructions to blink voluntarily whenever the CS was presented. A comparison of the latencies of these responses, which are known to be voluntary, with those of the conditioning groups should indicate whether the data are contaminated to any important degree by voluntary responses.

Subjects and procedure.—The *Ss* were 30 Duke University undergraduates who volunteered from the introductory psychology classes before discussion of conditioning. Six *Ss* were randomly assigned to each of five experimental conditions.

For all *Ss* the series of events in the experimental procedure was the same. First, the instructions, which were the same as those used previously, were read. After adjustment to the apparatus, *S* received 10 test trials with the CS alone. Following a 1-min. rest, *Ss* in the different groups received 3, 5, 10, 20, or 30 conditioning trials in which the CS and UCS were paired. The maximum number of conditioning trials was limited to 30 on the basis of the data previously reported (**2**). All *Ss* then received 35 presentations of the UCS alone. A series of 30 extinction trials (CS alone) began 15 sec. after the last presentation of the air puff.

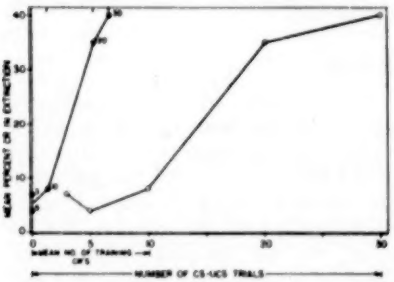

FIG. 1. Percentage of CRs in 30 extinction trials as a function of the number of trials (right-hand curve) and the number of CRs (left-hand curve) before the UCS trials. The numbers on the left-hand curve refer to the number of conditioning trials before the UCS trials.

Results and Discussion

The distribution of response latencies obtained in this study (including Exp. II) indicates that true CRs were being studied. Responses such as Beta responses and voluntary responses, which may distort the results of conditioning studies, occur with latencies predominantly under 300 msec. The median latency of the CR distribution in this study was 425 msec., and only 4.7% of the latencies were 300 msec. or shorter. No *S* qualified as a "voluntary responder" under Spence and Taylor's (**4**) criterion. For an interstimulus interval of .5 sec., they define a voluntary responder as an *S* who gives 50% or more responses with latencies under 300 msec.

The group of 5 *Ss* instructed to respond voluntarily to the CS, on the other hand, produced a latency distribution with a median of 270 msec., with 84% of the latencies in this distribution 300 msec. or shorter.

Figure 1 presents the main results of Exp. I in two ways. The right-hand curve is a plot of the percentage of CRs obtained in extinction as a function of the number of CS-UCS trials prior to the 35 air-puff stimulations. This curve seems to have reached an upper limit after 20 conditioning trials. Although there are significant differences among the various groups ($F = 32.09$; $P < .001$), the points obtained for the 20-trial and 30-trial groups are not significantly different ($t = .97$).

During the initial CS-UCS trials, the different groups gave different

numbers of CRs. For the 3-, 5-, 10-, 20-, and 30-trial groups the mean numbers of CRs were 0, 0, 1.3, 5.1, and 6.3, respectively. These numbers provide the abscissa points for the left-hand function in Fig. 1, where the percentage of CRs in extinction is plotted against the number of CRs in training. That is, the same percentages as in the right-hand function are plotted against number of CRs before the air-puff trials at the left of Fig. 1. Since the percentage values plotted in the left-hand function are the same as those in the right-hand function, the statistical statements which apply to the right-hand function also apply to this one.

The two curves presented in Fig. 1 suggest two different ways of considering the acquisition function for eyelid conditioning. One view would take the number of conditioning trials as the major independent variable; the other would regard conditioning as depending more directly upon the previous occurrence of a specified number of CRs. Preference for one of these positions over the other ultimately depends upon their relative values in producing laws of learning. At the same time, the curves in Fig. 1 suggest that the number of CRs is perhaps the more important variable because the number of responses in extinction increases much more rapidly with increasing numbers of CRs than it does with increasing numbers of trials. This interpretation, however, rests upon an *ad hoc* analysis involving the mean number of CRs during training. Experiment II is a more direct study of this idea, using exact numbers and a greater range of CRs as the independent variable.

Experiment II

In this experiment the procedure was to allow different groups of *Ss* to make different numbers of CRs in a series of CS-UCS trials before a series of air-puff trials. After the air-puff trials an additional series of CS-UCS trials and extinction provided data on the effect of introducing the UCS trials after different numbers of CRs.

Method

Except for the way in which the independent variable was manipulated and the manner in which its effect was measured, the method employed in this experiment was identical with that of Exp. I.

Procedure.—A total of 84 *Ss*, in 7 groups of 12 each, participated in this experiment. Each group first received 10 test trials. Then 6 of the groups received enough CS-UCS trials to produce a predetermined number of CRs, which, for the different groups, were 0, 1, 2, 3, 5, or 10. Each of these groups then received 20 trials in which the UCS was presented alone. The 0-CR group received the UCS trials before any CS-UCS conditioning trials. Except for the 0-CR group, the UCS trials were followed by enough additional CS-UCS trials to make a total of 60 trials, including the 20 UCS trials. Finally, each group received 30 extinction trials. The number of CRs was limited to 10 and the number of UCS trials to 20 in order to keep the total number of training trials at 60, as employed in the earlier study using a similar procedure. The 0-CR group received 60 CS-UCS trials and 30 extinction trials following the 20 UCS trials so that its performance over a long series of trials might be compared with a seventh, control group. The control group received 60 conditioning trials followed by 30 extinction trials; it did not receive any unpaired UCS presentations.

Results

The results of the experiment appear in one form in Fig. 2, which shows the percentage of CRs obtained in the first 10 CS-UCS trials following the unpaired air-puff trials, plotted as a function of the number of CRs prior to the air-puff trials. The function is negatively accelerated and increasing, reaching an apparent upper limit after about 3 CRs. An analysis of variance reveals that there are significant differences among the points represented in Fig. 2 ($F = 63.64$; $df = 5,66$; $P < .001$). An

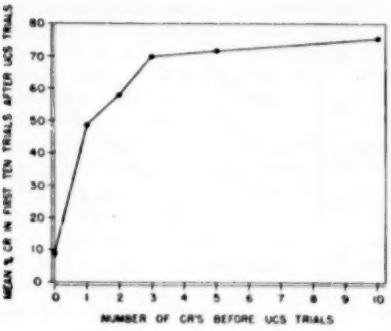

FIG. 2. Percentage of CRs in the first 10 trials after the UCS trials as a function of the number of CRs before the UCS trials.

evaluation of the differences among individual points, by means of a t test using an error term based on the within-group variance in the analysis above, shows that no significant differences exist among the 3-, 5-, and 10-CR groups. Although the 1-CR and 2-CR groups do not differ significantly, they are both reliably ($P < .01$) lower than the 3-, 5-, and 10-CR groups.

An analysis of variance performed on the number of CRs obtained on the last 10 CS-UCS trials (51–60) showed that the differences among the groups at this point were no longer significant ($F = 2.26$). Similarly, there were no significant differences in the extinction measures ($F = .51$). This lack of significance again reflects the fact that the acquisition function is asymptotic after 3 CRs. Since all *S*s gave at least 3 CRs prior to trial 51, and at least 11 before extinction, learning was complete prior to Trials 51–60, and no differences beyond Trial 51 or in extinction are to be expected.

The suggestion that the progress of conditioning depends upon the number of CRs rather than the number of training trials receives more direct support in this experiment. To test for a possible influence of the number of *trials*, the following analysis was made. For the 1-, 2-, 3-, 5-, and 10-CR groups, the *S*s were divided into two subgroups: those who took fewer than the median number of trials to produce the required number of CRs and those who took more than the median number of trials. For these two subgroups, the mean numbers of CRs occurring in the first 10 CS-UCS trials after the UCS trials were almost identical, 6.4 and 6.5. The mean number of trials required by these two subgroups to produce the CRs were 13.4 and 18.8, respectively.

A comparison of the performance of the control group (which received no UCS trials) with that of the 0-CR group appears in Fig. 3, which also includes for the other groups all of the points after the air-puff trials that could be plotted in trials by tens without eliminating *S*s. Since different *S*s required different numbers of initial CS-UCS trials to produce the requisite number of CRs, and since the total number of trials was 60, some *S*s in the 10-CR group received fewer than 20 CS-UCS trials after the UCS trials. For this reason there is only one point for the 10-CR group, and two for the other groups. The first points in Fig. 3 are the same points as are plotted in Fig. 2.

The comparison of the 0-CR group with the control group in Fig. 3 shows that the latter group consistently performed at a higher level. The difference in total number of CRs attains statistical significance ($t = 3.73$; $P < .005$). This result agrees with a previous report (**3**) that a series of UCS trials before conditioning interferes with subsequent learning.

Discussion

The results of these two experiments provide a general confirmation of the line of interpretation offered for the experiments in the earlier paper. They show that the associative process in eyelid conditioning develops much more rapidly than the usual learning curve would lead one to believe. They also necessitate a modification of the specific position taken in the previous paper, which was that the associative process develops with the number of conditioning trials. The results of these experiments show quite clearly that the number of previous CRs is the important variable; the interpretation offered in the earlier paper, and supported by the results of Exp. I, that conditioning is complete in 20 *trials* is correct only because 20 trials are enough to insure the occurrence of at least 3 CRs before the introduction of the UCS trials.

This evidence bears upon the theoretical question of the nature of the associations formed in eyelid conditioning. If the number of trials were the determining variable, this would support the (S-S) view that the associations are between the CS and UCS which occur together *on* every trial. The present results, however, lend more support to the (S-R) view that the associations are between the CS and the CR. Certainly, increasing the number of CRs by a given amount produces a greater change in behavior than an equal increase in the number of trials.

In this connection, Voeks (5) has recently presented data which point to the occurrence of CRs as an important determiner of the process of eyelid conditioning. From 50% of her *S*s, she obtained step-wise functions which reached 100% with the occurrence of the first CR. Our results agree with hers in suggesting that the occurrence of CRs is the significant determiner of conditioning. We have not, however, been able to duplicate her step-wise functions. The curve in Fig. 2 is clearly increasing gradually, although rapidly. Detailed examination of the data for the 20- and 30-trial groups in Exp. I and the 10-CR group in Exp. II fails to reveal any cases of step-wise conditioning. This difference in results may derive from any of a number of procedural differences between the two studies.

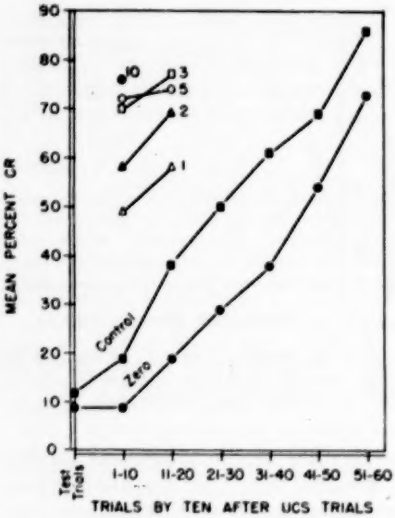

FIG. 3. Conditioning curves for all groups in Exp. II. Except for the control group, which received no UCS trials, the curves are for trials by tens after the UCS trials. The curves present all of the data which can be plotted without eliminating *S*s.

This experiment was not designed to study the motivational factor which is believed to be produced by the unpaired air-puff stimulations, and offers important information on only one point. The fact that the performance of the 0-CR group was consistently inferior to that of the control group shows that a series of air puffs prior to conditioning interferes with learning. Previous investigators obtaining the same result have interpreted it in terms of adaptation to the UCS, which is almost exactly opposite to the present interpretation in terms of increasing motivation. The hypothesis that the air-puff trials produce an increase in drive will handle this result if it is assumed with Spence and

his associates (e.g., 1) that drives energize *S*'s dominant habit, whatever it is. It is certain, on the basis of test trials, that, before conditioning, this dominant habit is not the CR. At this point the air-puff stimulations would not be expected to facilitate conditioning. Indeed, if the dominant response to the CS is antagonistic to the CR, the effect of increasing *S*'s motivation would be to interfere with subsequent conditioning. After a series of conditioning trials, the CR becomes the dominant response to the CS. At this point the effect of increasing *S*'s drive will be to increase the number of CRs, as it did in the previous study (2) where this interpretation was developed.

Summary

The two experiments reported in this paper studied the development of the associative process in eyelid conditioning. The technique was that of giving initial training in trials where the CS (a dim light) and the UCS (an air puff) were paired, and then presenting the UCS alone for a series of trials. The strength of conditioning was measured in extinction in Exp. I, and in a series of further conditioning trials in Exp. II.

In Exp. I, five groups of 6 *S*s each received 3, 5, 10, 20, or 30 conditioning trials, 35 UCS trials, and 30 extinction trials. Resistance to extinction was found to increase with the number of initial conditioning trials up to 20. A more detailed analysis indicated that the number of CRs in the initial trials was the important determiner of resistance to extinction.

In Exp. II, 6 different groups of *S*s received trials in which the CS and UCS were paired until they produced 0, 1, 2, 3, 5, or 10 CRs, followed by 20 air-puff trials. All groups except the 0-CR group then received enough additional CS-UCS trials to bring the total to 60, and 30 extinction trials. The 0-CR group received the 20 air-puff trials before 60 CS-UCS trials and 30 extinction trials. A seventh, control, group received 60 CS-UCS trials and 30 extinction trials without any UCS trials. A comparison of this latter group with the 0-CR group showed that, under these circumstances, the UCS trials interfere with conditioning. For all other groups, the UCS trials were facilitating. Performance in the first 10 trials after the UCS trials increased with the number of previous CRs up to a limit reached with the occurrence of 3 CRs. The results are treated as supporting an S-R view of classical conditioning.

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SKIN CONDUCTANCE AND PERIPHERAL VASCULAR REACTIONS

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Many hypotheses have been advanced in connection with the psychological import and concomitants of changes in skin conductance. Perhaps most of these points of view—whether the GSR is considered as an indication of a preparation for action, of conative activity, as a preparatory and facilitatory reaction, as an indication of an exploratory mental activity, or of emotional activation—may be reconciled by regarding changes in skin conductance in relation with the concept of organismic tension.

In this connection we wish to distinguish between two phases of reaction to any stimulus. First, there is the immediate arousal reaction which is mainly one of attending and of an exploratory nature before the significance of the stimulus is realized, which also implies psychological mobilization to attain a state of general mental preparedness, and which, insofar as the energy made available or the tension arrived at is concerned, may far exceed the actual requirements.

After this first phase, which may be very fleeting or even of vestigial nature as in habitual and reflex reaction, there follows either complete relaxation of the tension aroused in the first phase, or a period of uncertainty and conflict causing further increase in tension, and/or goal-directed and more or less sustained mental activity at a level of tension commensurate with the nature of the activity undertaken.

Both these phases represent forms of psychic tension but differ, nevertheless, in important respects. It is hardly necessary to point out that there are affective elements present in each case. Every communication received from the environment gives rise, in the first reactive phase, to a measure of uncertainty and thus constitutes a potential threat to the self. During the second phase there is a challenge to the self involved, which must prove its ability to perform the activity required. A certain degree of emotional tension is therefore inevitably present.

The first phase of these reactions to a stimulus represents the psychological aspect of preparation for action which may also be described as mobilization; the second phase represents the actual activity or the utilization of the energies so mobilized, or, alternatively, demobilization.

A similar picture is revealed by the physiological aspect of reaction. The immediate reaction again consists of a general mobilization, an increase of tension and activity in all systems and organs involved in possible reactions, with inhibition or suspension of activities in others not so involved. Thus there arises increased general tension in the skeletal musculature and increased tension in smooth muscles, which, again, implies increased activity in certain organs and changes in glandular functioning. These immediate and generalized reactions constitute the first reactive phase.

During the second phase the reaction becomes more specialized. Relaxation may follow, or the tension may be retained, increased, or decreased to the level required, in those voluntary muscles employed in the specific reactive behavior. The organism as a whole re-

mains in a hypertensive state at least as long as the situation retains its reaction-demanding nature and the special activity has to continue.

Both the initial alert signals for general mobilization (first phase) and the impulses ensuring specific reaction (second phase) travel to the organs concerned via the nervous system. As far as the nerves are concerned, increased tension simply means increased activity, that is, a higher frequency of impulses carried than is required normally for sustaining basic resting tonus and rhythmical functions.

It should be clearly realized that in the autonomous nervous system tension means increased activity *in both divisions*. Although activity of the sympathetic and parasympathetic divisions are usually regarded as antagonistic, Gellhorn (**4**) draws attention to the synergistic nature of their activity in connection with energy mobilization and utilization. This is, for example, apparent in connection with the blood-sugar level. While heightened sympathetico-adrenal activity is inclined to increase the concentration of blood sugar, increased activity of the vago-insulin system has the opposite tendency on account of the increased production of insulin. Gellhorn refers to the work of Soskin and Levine (**6**) who showed that the utilization of glucose depended not only on the amount made available in the blood, but also on the amount of insulin present. Only when a hyperglaecemic condition, as brought about by sympathetico-adrenal activity, is accompanied by increased production of insulin as caused by parasympathetic activity, can a maximum production of energy be attained. This synergistic functioning of the two systems under tension-producing conditions, however, usually demands a predominance of sympathetic activity so that on the whole the hyperglaecemic condition may be sustained notwithstanding increased insulin production. The resultant predominance of sympathetic activity may easily mask the fact that parasympathetic activity has nevertheless also increased.

In many physiological functions, e.g., peristalsis, the two systems have directly opposite effects, and increased activity in either or both can only be demonstrated by catching the two systems off balance, as only a disturbance of balance has any effect on the function concerned. A proportionate increase of activity in both would then be difficult to demonstrate by measurements of such a function.

A state of heightened tension may then, in the case of the vegetative nervous system, consist of either (*a*) a disturbance of the balance in the activities of the two systems, caused by a predominant increase in one of them accompanied by relatively smaller increase in the other; or (*b*) increased activity in both, without disturbance of balance.

Two valuable measures of autonomic activity are available in peripheral vascular reactions and electrical conductance of the palmar surfaces. Changes in both of these are usually regarded as dependent on sympathetic stimulation, as the presence of parasympathetic fibers in the limbs has never yet been demonstrated. Indications of disturbance of balance between the activities of the two systems are, however, not dependent on the presence of both kinds of fibers in an organ, as each system of nerves forms part of the larger system including hormonal activity, as indicated above, so that the effect of increased activity of either may also be brought about by humoral means.

The author has almost invariably found sympathetic predominance during the first phase of reactive tension; during the second phase differences appear, depending on the nature of the stimulus and associated emotions and on the individual make-up of *S*. This is entirely in agreement with the considerations presented above. Some investigations in this connection will now be described.

Method

The two measures of autonomic activity already referred to were utilized, the instruments employed being an optical finger plethysmograph and a psychogalvanometer to be described in a later publication. Simultaneous superimposed records were made photographically.

If finger volume changes as well as skin conductance were functions of vasomotor changes, the two measures should yield similar results. Even if both reactions were similar insofar as both were brought about by sympathetic impulses although the effector mechanisms were different (vasomotor and sudomotor respectively), one could expect more or less corresponding records, apart from differences in latency and adaptation rate which might be inherent in the respective effectors.

In Series I attention was mainly devoted to the first phase of reactive tension described above, i.e., the immediate reaction to discrete stimuli. As far as conductance is concerned, this reaction forms the classical galvanic skin response.

A second series of experiments (Series II) was designed to effect a state of sustained tension. Instead of discrete stimuli of short duration, *Ss* were set a continuous mental task demanding uninterrupted concentration of attention and mental activity lasting some 10 min. A series of single digits was typed, one underneath the other, about 1 cm. apart on a long strip of white paper which was then mounted on a kymograph drum in such a way that the end of the series joined up with the beginning without perceptible break.

The drum was rotated behind a cardboard screen with a 1-in. slit, at a distance of 18 in. from *S*'s eyes, with the result that *S* could see only two digits at a time. These two had to be added and the answer said out aloud. Every new digit that appeared had thus to be added to the previous one. Three full rotations of the drum, requiring 120 answers in all, were provided, first at a speed of 50 sec. per revolution. The process was then repeated at two higher speeds (30 sec. and 20 sec. per revolution). Practice effect was found to be effectively reduced to a negligible minimum by an initial practice period for each *S*, which also provided opportunity for adaptation to the experimental situation, and at the same time ensured that in most cases the initial phase of reactive tension, including the GSR, had been terminated before recording was commenced. In this series the intent was to deal with phenomena of the second phase, viz., the actual, active, goal-directed utilization of energies in the execution of a continuous well-defined task. Sustained attention was required, and the psychic tension was increased by means of the two accelerations. At the 20-sec. speed some *Ss* gave up the attempt, while others had to skip some figures. In any case the subjective tension was brought to a high pitch, as was afterwards reported by most *Ss*. Only intense concentration and effort could enable anyone to cope at all with the requirements in this case.

The *Ss* consisted of 30 male university students of ages 17 to 23 yr.

Results

Series I.—It was found that in the vast majority of cases tension caused by the application of the stimulus was accompanied by vasoconstriction (as indicated by decrease in finger volume and pulse volume) and increased skin conductance. Both of these reactions are now generally regarded as evidence of increased sympathetic stimulation. These effects were produced regardless of whether the stimuli were of auditory (electric bell), visual (light flashes), tactual (pressure applied) or mental (what is 3×5?) nature.

In the first phase of reactive tension plethysmographic and psychogalvanometric results in the main thus apparently agree, although even here certain anomalies and inconsistencies appear which make it abundantly evident that the effector mechanisms at least cannot be identical although we cannot agree that the two phenomena "are not related in any systematic way" as regards occurrence or amplitude.

Series II.—Fourteen records showed an over-all increase in skin conductance which may be regarded as an indication of increased sympathetic activity and of heightened physical tension. In nine cases the conductance, apart from temporary fluctuations, remained practically unchanged. In five cases there was an over-all decrease. Two cases were,

for various reasons, difficult to classify and are omitted.

The average change in conductance for all 30 cases was a statistically significant increase ($P < .01$).

This finding is contradictory to that of Duffy and Lacey (**3**), who found that the initiation of the task always caused an initial increase in conductance followed by a more or less continuous decrease during the course of the task, which they ascribe to adaptation. Here only 5 out of 30 records agreed with Duffy and Lacey's finding. The opposite results obtained in the present investigation might possibly have been brought about by the nature of the experimental situation which was designed with a view to eliminating adaptation by allowing sufficient time for almost complete adaptation before commencement of recording and by the nature of the task which was calculated to step up tension by means of acceleration.

Plethysmographic records showed an over-all decrease in finger volume, and therefore vasoconstriction, in 4 cases; in 3 the volume, apart from temporary fluctuations, remained more or less constant; and in 23 cases there was an over-all increase in volume and therefore vasodilation.

If vasoconstriction is regarded as indicative of increased sympathetic stimulation, we find a comparison of individual records yielding the following results: (*a*) Psychogalvanometric and plethysmographic records agreed in 11 cases, of which 3 were cases of increased tension according to both measurements, 3 other cases showing little change, and 5 cases of decrease in tension according to both measurements. (*b*) The two records disagreed in 17 cases. Of these, 11 indicated sympathetic activity according to conductance measurements but decreased tension according to finger-volume changes, 6 showed virtually constant conductance but definite vasoconstriction, and 2 cases were undecisive.

The evidence of these two series of experiments can be summarized as follows: (*a*) During the first phase of reactive tension both vasomotor as well as conductance measurements reflect predominantly increased sympathetic activity. Differences were found in reaction time, latency period (even for different stimuli on the same *S*), relative amplitude of reaction and recovery rate. Often recovery in one respect was still in progress while the other function already revealed evidence of renewed stimulation. On the whole this phase can, however, be characterized as one of general agreement in trend. (*b*) During the second phase apparently contradictory results are much more frequent than agreement, and these contradictions persist over relatively long periods of active change and do not merely concern recovery swings.

Discussion

These results clearly indicate a fundamental difference between palmar conductance and peripheral vascular changes. They also serve to differentiate the two reactive phases postulated before. The psychological situation concerned with these divergent reactions and the subjective experience of tension are, however, identical. The problem therefore remains to determine at what level these differences and apparent contradictions arise.

Clearly the effectors concerned in the two reactions cannot be identical. Attempts to explain the different results in terms of differences in latency and adaptation rate, or of differences in reactivity threshold of two different effector mechanisms (vasomotor and sudomotor) also fail, before ever-new

contradictions. It further follows that we are dealing not only with different effector organs but also with differences in stimuli influencing these organs. It is impossible to explain both reactions as the result of simultaneous and similar changes in the activity of sympathetic nerve fibers.

A possible explanation could perhaps be found in the problematic presence of sympathetic vasodilator fibers to the peripheral vascular system in addition to the well-known vasoconstrictor fibers. The existence of such fibers have been conclusively proved by Barcroft (2) and others in the case of the skeletal musculature, but it appears very unlikely that the blood vessels of the skin are served by them (1).

Another possible explanation may be sought in the humoral stimulation always accompanying autonomic activity.

In this connection the amines, more especially adrenalin and noradrenalin, have to be considered. Barcroft and Swan (2) have shown that adrenalin, contrary to expectation, has in the long run a dilatory effect on the peripheral vessels, which serves as homeostatic mechanism to prevent excessive increase in blood pressure. This fact would have provided an easy solution to the present paradox if it could be shown that adrenalin directly affected blood vessels but not sweat glands.

It appears, however, that the vasodilation in this case is brought about, not by direct local action of the adrenalin, but indirectly by a central inhibitory influence of the adrenalin on sympathetic activity, which would therefore also influence sweat-gland activity.

Adrenalin production is, however, only one of the hormonal reactions. Actually the whole of the endocrine system is involved in a highly complex way. It is now known, e.g., that locally formed substances such as sympathin and acetylcholine cause vasomotor effects, the former of sympathetic nature, the latter definitely vasodilatory. Richards is of the opinion that the minute vessels of the skin "are regulated chiefly by locally produced metabolites" (5, p. 17). It is difficult to determine whether such substances, which are liberated in very small quantity, usually by the nerve endings themselves, could, for example, produce a parasympathetic type of reaction in an organ quite devoid of parasympathetic nerves. That such effects can be brought about by some means or other have been conclusively shown. Insulin is, of course, another hormone with dilatory effect on peripheral vessels and produced in much larger amount. Again we refer to Richard's view that vasodilator mechanisms are mainly humoral (5, p. 19).

These considerations lead to the following tentative hypothetical explanation of the present paradoxical experimental results. If we assume that increased tension implies increased activity in both sympathetico-adrenal and parasympathetic-insulin systems, that sympathetic stimulation predominates during the first or mobilization phase, that afterward during the second phase, that of utilization of energy, there is a tendency in the direction of a return of balance by reason of the increased parasympathetic activity gradually catching up with the sympathetic, although both systems continue functioning at above-normal rate, that although both vasomotor and sudomotor functions are directly activated by sympathetic stimulation, the vascular condition is furthermore also influenced by humoral changes in the blood, at least to a greater extent than are the sweat glands—then it might be expected that something of the following nature happens: (*a*) During the first phase of indubitable sympathetic predominance, both vascular and conductance reactions would reflect increased sympathetic activity as a result of direct nervous stimulation as well as of possible hormonal influences. (*b*) During the second phase the condition of the blood vessels would reflect the return toward balance between the two systems as a result of the increased liberation of the parasympathetic type of hormones, such as insulin and acetylcholine, which gradually catch up on the initially increased liberation of the

adrenalin-sympathetic type of substances. In the meantime the skin conductance changes would continue to reflect the persistently increased sympathetic nerve-fiber activity, relatively little influenced by the gradual strong increase in parasympathetic activity.

In other words, the vascular reactions would provide an indication mainly of disturbed balance between the activities of the two divisions of the autonomic nervous system, while skin conductance reactions would indicate mainly changes in activity of the sympathetic division alone, quite apart from the balance situation.

Summary

Simultaneous records of finger volume (optical finger plethysmograph) and skin conductance (psychogalvanometer) were obtained from 30 *Ss* as immediate reactions to discrete stimuli and as reactions associated with sustained tension produced by increasingly fast-paced mental addition. During the first phase of reactive tension, both vasomotor and conductance measurements reflect predominantly increased sympathetic activity. During a second phase, which is associated with sustained goal-directed mental activity, contradictory results are obtained from the vasomotor and conductance indices. An explanation of these findings is attempted.

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EFFECTS OF VISUAL, VESTIBULAR, AND SOMATOSENSORI-MOTOR DEFICIT ON AUTOKINETIC PERCEPTION [1]

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There has been considerable controversy of late concerning the relative contribution of the various sensory modalities in visuo-spatial perception. Asch and Witkin (**1, 2, 35, 36**) reported that the most marked effects upon the subjective coordinates of visual space were produced by altering the optical environment. In contrast, Mann, Passey, and collaborators (**20, 24**) found that lateral tilting of the body resulted in the greatest subjective effect, unless the optical environment was unusually compelling (**19**). In still other studies of spatial perception, the significance of vestibular stimulation and its effects on the oculomotor system have been stressed. Graybiel and coworkers (**9, 10**), Mann (**21**), and Wendt (**31**) have all pointed out that autokinesis is influenced by Barany rotation (the oculogyral illusion), the direction of apparent movement corresponding to the various components of nystagmus during and after rotation. Recently, Wapner and Werner have shown that changes in the perception of extrapersonal space can be induced by electric stimulation of the neck muscles (**28**) and by asymmetric optical stimuli (**30, 34**), as well as by the usual body tilt (**32**) or Barany rotation (**29**). In their opinion (**33**), body tonus forms the basis for all of these effects, since spatial perception is considered the resultant of an "organismic" equilibrium between tonic state and sensory stimulation ("sensory-tonic" theory). Unfortunately, the physiological mechanisms which presumably subserve this process are not specified.

In reviewing most of the foregoing studies, Gibson concluded that "The question is no longer which mode (of stimulation) is *decisive* when they are set in conflict but simply how do they interact?" (**7**, p. 372). From this point of view, observations on neurological material can be helpful, since qualitative alterations in spatial perception are often seen in such cases. There have been numerous clinical reports, for example, of subjective distortions in the visual perception of space in patients with vestibular or brain-stem disease (**6**). In fact, on the basis of extensive observations (**12, 13, 15**), Halpern has suggested (**14**) that these visual distortions are directly attributable to a disturbance in body posture.

Patients with lesions above the tentorium may also exhibit visuo-spatial difficulties. Lesions of the parietal lobe, in particular, have been credited with producing many forms of spatial deficit (**5**). More subtle changes in the visual perception of space have been reported in patients with lesions restricted to the geniculocalcarine projection system. In these cases, alterations in the perception of distance (micropsia or macropsia) or form (metamorphopsia) have been found in those portions of the visual field which appear normal on perimetric examination (**4**). Even lesions

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involving the anterior cerebral substance have been said to result in defective visuo-spatial perception when special methods of testing are used. In such cases both Bender and Jung (**3**) and Teuber and Mishkin (**27**) have found that tilting or deviating the body produces slight but significant alterations in the perception of the optical vertical. These findings are difficult to interpret, however, since their relationship to the neurological symptoms of the patients were not evaluated.

In summary, visual, postural, and vestibular stimulation has been shown to affect the visuo-spatial perception of normal *S*s. The manner in which these influences are mediated, however, is not clear. In patients with damage of the central nervous system, many forms of visuo-spatial alteration have been described but not specifically related to either neurological status or to the nature of the secondary stimulus. Nevertheless, according to the foregoing considerations, definite predictions can be made concerning this relationship. One would expect, for example, that rotation of the patient with decreased labyrinth sensitivity would result in little change in the visual perception of space. Similarly, patients with postural deficits due to hemiparesis or hemisensory syndromes should manifest minimal alterations in visual perception when the body is tilted or deviated laterally. When only optical stimuli are utilized, one would expect patients with visual field defects to differ most widely from controls.

The present investigation attempted to test the three hypotheses given above, using the autokinetic phenomenon as an index of subjective visuo-spatial extent.

Method

Subjects.—A total of 65 *S*s were tested. Fifty-five of these were randomly chosen patients from the neurological and neurosurgical services of the Mt. Sinai Hospital; the remaining 10 were "normal" controls composed of hospital personnel. On the basis of the symptoms demonstrated on neurological examination, the following groups were constituted: Group NC, normal controls without evidence of neurological disease; Group SC, patients with unilateral sensory and/or motor symptoms referable to lesions of the spinal cord or its roots: Group HV, brain-damaged patients with homonymous visual field defects upon perimetry; Group SM, brain-damaged patients without visual field defects but with frank hemisensory syndromes and/or hemiparesis; Group OM, patients with unilateral alterations in the oculomotor response to caloric stimulation of the labyrinth.[2]

Apparatus.—The experimental situation is illustrated in Fig. 1. The stimulus light, a dim spot 4 mm. in diameter, was projected upon the center of an opal glass screen (SC) from the rear. This screen was calibrated in degrees of arc (in both horizontal and vertical planes), in terms of a tangent projection of *S*'s monocular field of vision. By means of a double-throw switch, the stimulus bulb (B1) and an electric timer (T) could be de-energized and two field bulbs (B2 and B3) turned on which transilluminated the entire glass. A head and chin rest, pivotable about its center, was placed 30 in. distant. By means of this instrument *S*'s head or trunk, or both, could be deviated around the cephalo-caudal axis, and the angular displacement from the plane normal to the glass screen read from a scale (± .5°). For rotational stimulation, the chin rest was removed and *S* turned by hand at approximately 1 rps for 10 turns. He was then repositioned so that the median plane of the body coincided with the normal to the center of the screen.

All *S*s viewed the stimulus light monocularly, using the eye on the "affected" side of the body; i.e., the side with the somatosensory or motor symptoms, defective labyrinthine function, or temporal amaurotic field of vision. For those conditions where the head was deviated from the plane normal to the glass screen, the eye was turned in its orbit so that direct fixation of

[2] Included in this group were eleven cases with known involvement of the brain stem (cerebellar tumors, acoustic neuromas, midbrain aneurisms or vascular accidents), plus four cases with decreased vestibular sensitivity of unknown etiology.

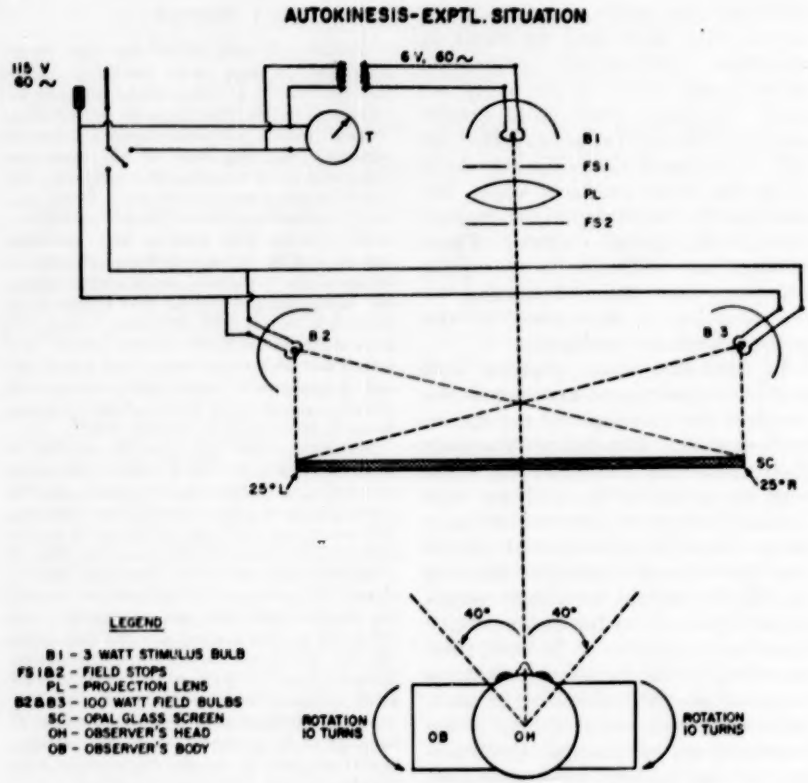

FIG. 1. Experimental situation.

the stimulus light was maintained. None of the patients, including those with hemianopia, had defects in foveal vision, and no obvious difficulties in maintaining fixation were encountered.

Procedure.—Each *S* was informed that his ability to see and remember the path of a moving light in the dark was to be tested. To emphasize the mobility of the stimulus light, *E* demonstrated various speeds and directions by moving it on the screen. The *S* was then instructed to report the first appearance of the stimulus light after the field lights were extinguished and when it started to move. He was also asked to report the general characteristics of the direction and speed of the light's movement while the trial was in progress. At the end of each trial, the field lights were turned on, and *S* was asked to trace on the screen the course the stimulus light had taken.

At the start of testing, all *S*s received one practice trial with the head and trunk in the straightforward (no deviation) position. For this and all subsequent trials, the stimulus light was exposed for 1 min. after *S* reported seeing it. After the practice trial, *S* viewed the stimulus under the following conditions of head and trunk deviation with respect to the vertical plane normal to center of the screen: (*a*) control (no deviation of head or trunk); (*b*) head 0°, trunk 40° to unaffected side; (*c*) head 0°, trunk 40° to affected side; (*d*) head and trunk 40° to affected side; (*e*) head and trunk 40° to unaffected side; (*f*) head alone 40° to unaffected side; (*g*) head alone 40° to affected side. Two trials were obtained for each of the above conditions; one

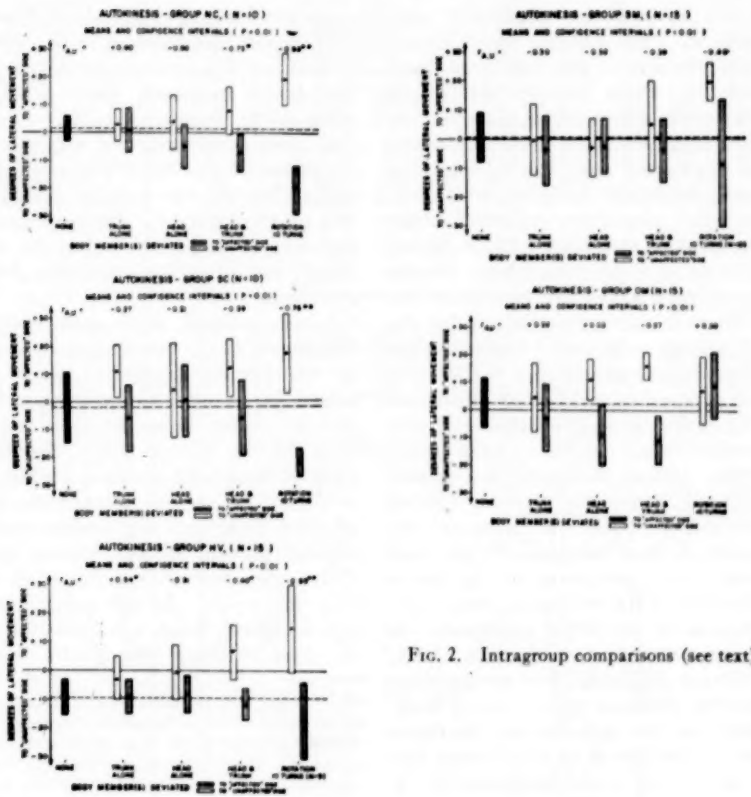

FIG. 2. Intragroup comparisons (see text).

in the order indicated, the other in reverse order after a rest period of several minutes. At the end of the testing session, two readings were taken after rotation; the first of these was toward the affected side, the last toward the unaffected side.[3]

At the conclusion of each trial the course of apparent motion, as traced by *S* on the glass screen, was plotted in degrees of arc in terms of the tangent projection of his visual field. The maximal degrees of perceived movement in the horizontal plane was recorded, using a positive sign for movement toward the affected side of the body, and a negative sign for the movement in the opposite direction (unaffected side). These two vectors were then added algebraically to yield a resultant, which was termed the lateral autokinetic response.

[3] These trials were always presented at the end of the session because preliminary studies indicated that some patients developed nausea after rotation and did not want to continue the testing procedure. For this same reason, patients who were acutely ill could not be rotated.

RESULTS

Intragroup comparisons.—The effects of the various testing conditions on autokinesis are illustrated per group in Fig. 2. In each graph, the group mean lateral autokinetic response and its confidence interval ($P = .01$) is plotted vertically in degrees of arc, with positive values (movement principally toward the unaffected side) above the zero line and negative values (movement prin-

cipally toward the unaffected side) below it. The various conditions of body deviation are indicated horizontally. Open bars on the graphs refer to the effects obtained when the body members were deviated toward the unaffected side, striped bars, the results when the deviation was in the opposite direction (affected side). The control condition (no deviation) is shown as a solid black bar. At the top of each graph are also given the product-moment correlations for the autokinetic responses obtained when the body was deviated in the affected as compared to unaffected directions.

In order to analyze the results in greater detail, *t* tests were made within groups between the effects obtained under the various testing conditions. Table 1 presents the results of these comparisons for each group, the sign given to the mean difference (MD) indicating the major direction of perceived movement resulting from the introduction of the various conditions. For comparisons between different conditions of body deviation, this sign denotes the direction of the change in autokinesis due to the second of the conditions given in the column headings.

The results illustrated in the figures and summarized in Table 1 show that trunk or head deviation alone had little effect on autokinesis in the normal *S* (Group NC). Head and trunk deviation combined, however, produced a large and significant shift in perceived movement toward the side opposite the direction of deviation. Rotation produced an even greater shift in apparent movement, the difference being significantly larger than the effects due to head and trunk deviation combined.[4] In cases with spinal cord lesions (Group SC), significant changes in the direction of autokinesis occurred only when the body members were deviated toward the unaffected side. Under the latter condition, the response to deviation of the head was negligible while that due to trunkal deviation was quite marked.[5] The response to Barany stimulation, however, was clearly significant for rotation in either direction.

More marked and more specific differences in the autokinetic response to the testing conditions were obtained in *Ss* with brain lesions. In patients with homonymous visual field defects (Group HV), the data show a large and significant shift in perceived movement toward the unaffected side, i.e., the perimetrically normal portion of the visual field, under the control condition of no body deviation. In this group, turning the trunk, head, head plus trunk, or even rotating the entire body

[4] In highly cooperative *Ss* there were three qualitatively distinct types of apparent movement noted following rotation. There was an initial 2- to 10-sec. period of "blurry" movement which was confined to the spatial vicinity of the stimulus light and which often appeared saccadic in nature. There then followed a smooth (non-saccadic), progressively accelerating and later decelerating, movement in the direction opposing rotation. This movement lasted for over a minute in most subjects and was readily identified by all. It was this longer-lasting second phase which was scored as the lateral autokinetic response to rotation. In some *Ss* there appeared a late third phase consisting of a slow gradual return of the perceived light toward the center of the field, frequently with an overshoot toward the other side. The possible relationship between the character of these three types of autokinetic response and the various phases of nystagmic eye movements during and after rotation has been discussed in detail by Wendt (**31**).

[5] This finding must be qualified by the observation that most of our spinal cord cases had lesions in the upper thoracic and cervical areas and complained of pain upon head deviation. Patients with lower spinal lesions were usually in traction or confined to bed and hence could not be tested.

TABLE 1

INTRAGROUP COMPARISONS OF LATERAL AUTOKINETIC RESPONSES (IN DEGREES)

Group	Body Deviations Compared															
	None vs. 0		None vs. Trunk		None vs. Head		None vs. Head & Trunk		None vs. Rotation		Trunk vs. Head		Head vs. Head & Trunk		Head & Trunk vs. Rotation	
	MD	*t*	MD	*t*	MD	*t*	MD	*t*	MD	*t*	MD	*t*	MD	*t*	MD	*t*
NC																
A	+ 1.4	1.00	− 0.5	0.18	− 6.3	2.17	− 8.3	3.32**	− 21.7	7.56**	− 5.8	1.67	− 2.0	0.61	− 13.4	4.01**
U			+ 1.4	0.61	+ 2.3	0.69	+ 6.4	2.27*	+ 18.0	5.59**	+ 0.9	0.26	+ 4.1	1.01	+ 11.6	2.93*
SC																
A	− 2.0	0.51	− 3.9	0.72	+ 2.3	0.41	− 4.0	0.70	− 19.7	4.71**	+ 6.2	1.14	− 6.3	1.09	− 15.7	3.52**
U			+ 12.9	2.65*	+ 5.8	0.89	+ 13.8	2.74*	+ 19.0	3.23**	− 7.1	1.19	+ 8.0	1.31	+ 5.2	0.96
HV																
A	− 9.3	4.41**	+ 0.2	0.07	+ 1.3	0.43	− 2.0	0.72	− 8.1	1.78	+ 1.1	0.37	− 3.3	1.17	− 6.1	1.38
U			+ 6.3	1.83	+ 8.7	2.23*	+ 16.0	4.27**	+ 24.0	4.72**	+ 2.4	0.56	+ 7.3	1.62	+ 8.0	1.44
SM																
A	+ 0.6	0.22	− 4.5	0.91	− 3.0	0.71	− 4.5	1.00	− 9.2	1.24	+ 1.5	0.29	− 1.5	0.31	− 4.7	0.60
U			− 1.0	0.20	− 3.7	0.85	+ 4.1	0.70	+ 19.0	5.59**	− 2.7	0.51	+ 7.8	1.27	+ 14.9	2.70*
OM																
A	+ 2.6	0.87	− 5.3	1.05	− 11.5	2.49*	− 13.3	3.11**	+ 6.4	1.29	− 6.2	1.13	− 1.8	0.39	+ 19.7	3.94**
U			+ 2.0	0.39	+ 8.5	2.19*	+ 13.2	3.84**	+ 4.5	0.89	+ 6.5	1.32	+ 4.7	1.55	− 8.7	1.98

* Significant at $P = .05$.
** Significant at $P = .01$ or better.
Note.—Direction of body deviation designated by: A, affected side; U, unaffected side.

toward the affected side, did not result in a significantly greater shift in autokinesis into the unaffected portion of the field. When these same conditions were used in the opposite direction, i.e., deviations toward the unaffected side, effects were obtained which are analogous to those in control *Ss*. These findings contrast rather markedly with the results obtained from patients with hemisensory deficits and/or hemiparesis (Group SM). In this group of patients there were no significant effects upon deviating the trunk, head, or head plus trunk in either direction. In fact, the only condition which produced a definite shift in the direction of autokinesis was rotation toward the unaffected side of the body.

The last group of *Ss* to be considered are those with evidence of unilateral impairment in vestibular function (Group OM). The graphical and tabular data indicate that these patients differed from all others in that no significant shift in autokinesis was obtained upon Barany rotation in either direction. By contrast, the responses of this group to passive deviation of the trunk, head, and head plus trunk were not only significant, but appeared even greater in magnitude than those obtained from control *Ss*.

Intergroup comparisons.—In order to evaluate the significance of visual, vestibular, or postural deficit upon the magnitude of the autokinetic response, additional *t* tests were made between groups for each condition of testing (Table 2). In these comparisons, mean differences between groups were taken algebraically, in the order given, so that their signs indicate the direction of the differences in autokinetic response between groups (positive values, perceived motion more toward the unaffected side, negative values the reverse). The results of these comparisons show that Groups SC and NC differed in only one respect, namely, the response of the former to deviation of the trunk toward the unaffected side of the body. For this one condition, Group SC manifested a response paradoxically greater than that of the normal group.[6] For purposes of evaluating the effects of the neurological symptoms resulting from brain damage, the data from these two groups were therefore pooled as a combined control.

With reference to the combined control group, the data in Table 2 show that the visually defective patients in Group HV consistently saw movement closer to their perimetrically normal half fields (unaffected side). Only the differences obtained under the control condition of no body deviation and of deviation of the trunk to the unaffected side, however, turn out to be statistically significant. In contrast to these results, Group SM showed no effects which differed significantly from those of combined controls, even though some of the mean differences were rather large. This finding can be attributed to the marked interindividual variability which occurred within this group of patients with somatosensori-motor deficits. Patients with vestibular dysfunction (Group OM) differed significantly from controls for two conditions of testing. First, with the body rotated in either direction, the result obtained was not only significantly less than that of controls, but for one condition (rotation to affected side) was even in the opposite direction. Secondly, the patients in Group OM manifested a significantly greater response than controls when the head

[6] But see footnote 5.

TABLE 2

INTERGROUP COMPARISONS OF LATERAL AUTOKINETIC RESPONSES (IN DEGREES)

Body Members Deviated	Groups Compared													
	SC vs. NC		HV vs. SC + NC		SM vs. SC + NC		OM vs. SC + NC		HV vs. SM		HV vs. OM		OM vs. SM	
	MD	*t*	MD	*t*	MD	*t*	MD	*t*	MD	*t*	MD	*t*	MD	*t*
None	− 3.4	0.82	− 9.0	3.07**	+ 0.9	0.26	+ 2.9	0.80	− 9.9	2.86**	− 11.9	3.25**	+ 2.0	0.49
Trunk														
A	− 6.8	1.54	− 6.6	2.18*	− 1.4	0.30	− 0.2	0.04	− 5.2	1.14	− 6.4	1.42	+ 1.2	0.21
U	+ 8.1	2.37*	− 9.8	2.94**	− 7.2	1.60	− 2.2	0.48	− 2.6	0.53	− 7.6	1.51	+ 5.0	0.85
Head														
A	+ 5.2	1.10	− 5.7	1.77	− 0.1	0.02	− 6.6	1.51	− 5.6	1.44	+ 0.9	0.21	− 6.5	1.34
U	+ 0.1	0.02	− 4.4	1.00	− 6.9	1.55	+ 7.3	1.89	+ 2.5	0.53	− 11.7	2.83**	+ 14.2	3.38
Head & Trunk														
A	+ 0.9	0.19	− 4.9	1.65	+ 2.5	0.59	− 4.3	1.12	− 7.4	1.85	− 0.6	0.17	− 6.8	1.45
U	+ 4.0	0.95	− 3.1	0.83	− 5.1	0.92	+ 6.0	2.22*	+ 2.0	0.33	− 9.1	2.57*	+ 11.1	2.04*
Rotation														
A	− 1.4	0.47	+ 3.6	0.84	+ 12.4	1.76	+ 30.0	7.11**	− 8.8	1.10	− 26.4	4.67**	+ 17.6	2.21*
U	− 2.4	0.46	− 3.5	0.66	+ 1.4	0.43	− 11.1	2.30*	− 4.9	0.97	+7.6	1.23	− 12.5	2.76*

* Significant at $P = .05$.
** Significant at $P = .01$ or better.
Note.—Direction of body deviation designated by: A, affected side; U, unaffected side.

and trunk were deviated toward the unaffected side.

When comparisons are made among the brain-injured groups, results are obtained which are consistent with the above findings. Group HV differed from both Group SM and Group OM in that perceived movement was almost always closer to the unaffected side (normal half field of vision). Only the effect obtained under the control condition (no body deviation), however, was significant. Group OM differed significantly from Group SM under two conditions of testing. First, the patients in Group OM showed a markedly underactive response to rotation in either direction. Secondly, these same patients had a paradoxically overactive response to head and trunk deviation toward the unaffected side.

In summary, turning the body of the normal *S* to one side causes a shift in autokinesis in the opposite direction. Although minimal effects are produced by head or trunk deviation alone, turning the entire body results in significant changes in the direction of autokineses, particularly when Barany rotation is used. A decrease in somatosensori-motor or vestibular function after damage to the nervous system results in a selective loss in the respective effects of body position and of rotation, the latter deficit being most marked and most reliable. In patients with homonymous visual field defects, there is a consistent displacement of perceived movement toward the perimetrically normal half field. This unidirectional autokinesis can be partially overcome by deviating or rotating the body toward the normal half field, i.e., toward the unaffected side, but deviation toward the affected side produces negligible effects.

Discussion

The results of this study fit the concept that visual, vestibular, and somatosensori-motor stimuli interact in determining the subjective coordinates of visual space. Some of the physiological factors which may be involved in this interaction will be discussed, therefore, in terms of our findings.

Visual and oculomotor factors.—It will be recalled that the stimulus light was always directly fixated by the *S*s, and hence was presumably stimulating only the foveal area of the retina. Since the position of the eye in the orbit was not monitored, the possibility that some eye movements took place during fixation cannot be discounted. Such movements, if they did occur, could have produced changes in the subjective localization of the stimulus light due to successive stimulation of adjacent retinal locations during oculomotion. It is doubtful, however, that the amplitude of these eye movements could have been sufficiently great (10° to 30° of arc) to have resulted in the large shifts in subjective spatial location which were found upon body deviation. This interpretation is supported by qualitative observations on three cases with unilateral weakness of the internal rectus muscles and consequent partial paralysis of lateral gaze. All three of these patients reported autokinetic movement much farther laterally than their paralyzed eye could move. In the face of this evidence, and in view of the results of a previous study using photographic techniques (**11**), one can conclude that there is no direct relationship between the magnitude of perceived movement and the position of the eye in its orbit.

If the effects found in this study cannot be attributed solely to eye movements, then problems arise concerning the visual mechanisms involved. Traditional theories (**6, 22, 25**) of visual space perception assume a one-to-one relationship between subjective localization and the locus of excitation on the retina ("local sign"), and its corresponding topologic projection to the

striate cortex ("cortical retina"). The present data show that body deviation can produce wide shifts in perceived movement while the eye remains relatively fixed in position. This finding does not appear to be consistent with traditional theory. Moreover, the results obtained in patients with homonymous visual field defects (Group HV) also appear incompatible with the concept of a strict point-for-point projection of subjective spatial localization through the nervous system. Such patients tend to perceive autokinetic motion consistently in the direction of their perimetrically normal half field of vision. In fact, 13 out of the 15 *S*s in this group saw movement only in this direction on both trials of the control condition (no body deviation). In addition to these 15 patients, there was an opportunity to test three other cases with bitemporal field defects due to a lesion of the optic chiasm. Perceived motion in all three of these cases was always toward the nasal (uninvolved) half field irrespective of the eye tested. The above findings indicate that subjective visual location is a more complex phenomenon than a mere spatial projection of afferent impulses from a retinal "image."

Goldstein (**8**), among others, has pointed out that hemianopic patients tend to compensate for visual loss by slowly developing certain changes in body tonus, such as preferred head and eye positions. In the present study, only one patient with a hemianopia of long standing was tested. This patient was one of the two cases who perceived movement equally well to both sides of the visual field.[7] The possibility exists, therefore, that the present findings are characteristic of acute cases only and represent the fact that such patients have not had time to develop the preferred head or eye positions needed to compensate for their visual field deficit. If true, this hypothesis would imply that different results would be obtained in cases with hemianopia of long standing where sufficient time has elapsed for the development of adaptive tonic mechanisms.

Vestibular factors.—In the present study, the most marked influence on autokinesis was obtained upon rotational stimulation. This effect has been previously reported by Graybiel (**9, 10**) and by Wendt (**31**), both of whom have emphasized the role of eye movements in visuo-spatial perception. The present additional finding of a marked loss of this rotational influence in patients with vestibular dysfunction, confirms and extends the previous report of Mann (**18**), and is compatible with the numerous clinical observations of Halpern (**12, 13, 14, 15**) on alterations in visuo-spatial perception after brain stem or cerebellar lesion.

Despite the unanimity of experimental and clinical findings, the mechanism of this vestibular factor is still not clear. The simplest explanation would be one couched in terms of eye movements (nystagmus or tonic deviation of the eye) with resulting displacement of the retinal "image." This possibility already has been discussed and found inadequate. The problem is therefore raised as to other ways in which vestibular stimulation could exert its effect. In the group of patients with defective labyrinth function (Group OM), the symptoms of vertigo, nausea, falling to one side, and past-pointing were characteristically absent after caloric or Barany stimulation. This finding suggests that vestibular stimulation may alter the visual perception of space by means of its influence on body tonus. Such a postulation appears necessary moreover, in view of our finding that hemiparesis and/or hemisensory dysfunction tends to disrupt the normal perceptual response to Barany rotation when the patient is turned toward his affected side. That vestibular stimulation can affect the postural system of the body as been known for a long time. Early experiments by Magnus (**17**) and by Muskins (**23**) demonstrated that galvanic, caloric, or acceleratory stimulation of the labyrinth could directly alter the muscular tonus of the head, neck, and trunk.

[7] The other patient had a minimal peripheral amblyopia.

What other systemic (postural) effects vestibular stimulation can produce, and how these effects may influence spatial perception, remain problems for further study.

Postural factors.—Much has been reported of late concerning the effects of postural stimulation on visual perception (**2, 19, 24, 28, 29, 32, 34, 36**). The results obtained in this study confirm the general tenor of these previous reports, since it was clearly shown that cephalo-caudal deviation of the head and trunk reliably alters the direction of autokinesis. The afferent impulses which form the bases for these postural effects however, are still not clear.

The present data indicate that somatosensory and/or hemiparetic deficits due to brain damage (Group SM) can alter the effects of body deviation on autokinesis, but these alterations were small and relatively unreliable as compared to the effects of visual or vestibular dysfunction. This finding was mainly due to the great interindividual variability which occurred within Group SM. Some of the patients in this group showed a definite effect of body deviation on autokinesis, while others did not, or manifested equivocal changes. An attempt was made to relate this variability in performance to neurological data on the relative motor and somatosensory performance of these patients (including position sense), but no meaningful pattern of relationship was obtained. It was noted, however, that some of the patients in this group had relatively large lesions and showed marked mental changes. To what extent this may have contributed to the heterogeneity of the results is problematical. At present, therefore, one can only speculate as to whether kinesthesis, cutaneous sensitivity, or motor power plays the decisive role in producing the effects of body torsion on visuospatial perception.

Problem of interaction.—It was suggested above that the influence of vestibular stimulation on visual perception is mediated by means of changes in body tonus. Similarly, the possibility was discussed that an immediate alteration in visuo-spatial perception may occur in the patient with a hemianopia, and that in time this alteration is overcome as adaptive tonic mechanisms are developed. In addition, it has been pointed out that the sensory bases for these tonic influences are as yet ill defined. Nevertheless, it can be concluded that the visual perception of space involves an integration of the effects of visual, somatosensori-motor, and vestibular stimuli. The problem is clear: how does this integration take place?

Lashley (**16**) has pointed out that visual stimulation does not activate a quiescent nervous system, but produces afferent activity which becomes superimposed upon impulses arising from other sources. This point of view emphasizes the physiological complexity of the visual process and as such seems to fit our results much better than the concept of an insulated point-for-point projection of space through the nervous system. In terms of Lashley's concept, the present data would indicate that visual afferent activity is modified by vestibular and somatosensori-motor stimuli, both of which somehow alter the muscular tonus of the body. In fact, all of the present results could be explained if one postulates that the body acts as a frame of reference for spatial perception. This concept is not new. Concomitant alterations in the awareness of body members (defects in "body image") and in the visual perception of space have been reported after brain damage and have led to the same postulation (**5, 26**). The physiological problems of spatial perception can be stated, therefore, in terms of the factors which determine the bodily frame of reference and how it is modified by afferent activity in the nervous system. Further empirical studies are needed to determine the heuristic value of this concept.

Summary

The effects of visual, vestibular, and somatosensori-motor deficit upon autokinetic movement were evaluated in a series of 65 *Ss* under the

following conditions of stimulation: (*a*) control, (*b*) head alone turned to one side, (*c*) trunk alone turned to one side, (*d*) both head and trunk deviated to the same side, (*e*) Barany rotation.

In normal control *Ss*, results show that head or trunk deviation alone produces minimal effects on the direction of autokinesis; head and trunk deviation combined, however, produces a significant shift in perceived movement in the direction opposing that of the deviation. A greater effect is produced in the same direction by Barany rotation. In patients with visual deficit due to brain damage, autokinesis is predominantly toward the perimetrically normal half field, but can be reversed by turning the body in the appropriate direction. Vestibular dysfunction due to involvement of the brain stem results in a selective loss in the autokinetic response to rotation. Patients with somatosensori and/or motor deficits due to cerebral damage show little effect of body deviation upon autokinesis, including the response to rotation. There were marked individual differences, however, within this group.

These findings indicate that visual, vestibular, and somatosensori-motor stimuli interact in determining the visual perception of space. For reasons given, this interaction cannot be attributed simply to eye movements, but appears to be due to the influence of body tonus in determining visuo-spatial perception.

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Engineering Psychologist

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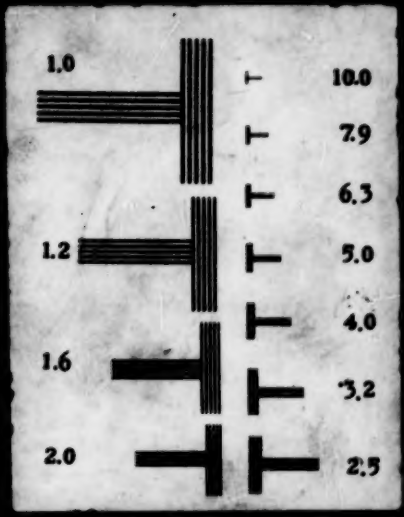
RESOLUTION CHART



100 MILLIMETERS

INSTRUCTIONS Resolution is expressed in terms of the lines per millimeter recorded by a particular film under specified conditions. Numerals in chart indicate the number of lines per millimeter in adjacent "T-shaped" groupings.

In microfilming, it is necessary to determine the reduction ratio and multiply the number of lines in the chart by this value to find the number of lines recorded by the film. As an aid in determining the reduction ratio, the line above is 100 millimeters in length. Measuring this line in the film image and dividing the length into 100 gives the reduction ratio. Example: the line is 20 mm. long in the film image, and 100/20 = 5.

Examine "T-shaped" line groupings in the film with microscope, and note the number adjacent to finest lines recorded sharply and distinctly. Multiply this number by the reduction factor to obtain resolving power in lines per millimeter. Example: 7.9 group of lines is clearly recorded while lines in the 10.0 group are not distinctly separated. Reduction ratio is 5, and 7.9 x 5 = 39.5 lines per millimeter recorded satisfactorily. 10.0 x 5 = 50 lines per millimeter which are not recorded satisfactorily. Under the particular conditions, maximum resolution is between 39.5 and 50 lines per millimeter.

Resolution, as measured on the film, is a test of the entire photographic system, including lens, exposure, processing, and other factors. These rarely utilize maximum resolution of the film. Vibrations during exposure, lack of critical focus, and exposures yielding very dense negatives are to be avoided.